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LETTERS OF EULER
ON
NATURAL PHILOSOPHY.

EDITED BY
DAVID BREWSTER, LL.D.

IN TWO VOLUMES.
VOL. I.

WITH ENGRAVINGS.

New-York:
J. & J. HARPER, 82 CLIFF-STREET.
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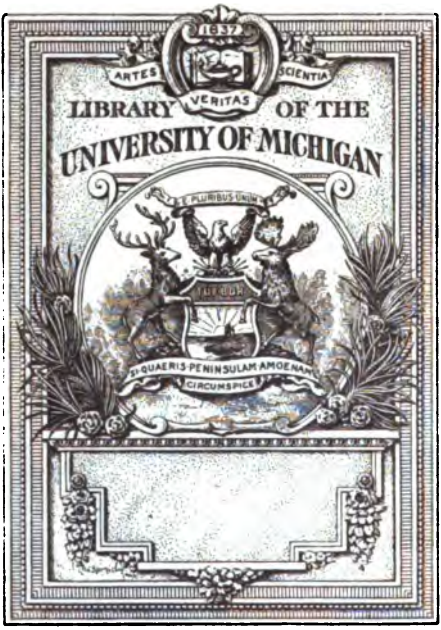

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LETTERS OF EULER

ON DIFFERENT SUBJECTS IN

NATURAL PHILOSOPHY.

ADDRESSED TO

A GERMAN PRINCESS.

WITH NOTES, AND A LIFE OF EULER,

BY

DAVID BREWSTER, LL.D.
F.R.S. LOND. AND ED.

CONTAINING A GLOSSARY OF SCIENTIFIC TERMS.

WITH ADDITIONAL NOTES,

BY JOHN GRISCOM, LL.D.

IN TWO VOLUMES.

VOL. I.

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EDITOR'S PREFACE.

The work now presented for the first time to the American public is the production of one of the most learned and highly-gifted men whose names adorn the annals of sound philosophy, and whose labours gained for him a reputation inferior only to that of Newton. They will be read with great advantage by the young student, on account of the remarkable clearness with which the subjects are treated, the copiousness of the style, and its adaptation to the purpose of easy and familiar instruction. The author, in addition to his profound knowledge, had the advantage of being, both by profession and by taste, a teacher of youth; and the volumes before us bear evidence of the tact which an experienced instructer acquires in discovering the points which stand most in need of varied and reiterated explanation.

The theories which the author endeavours often by elaborate reasoning to support are, it is true, in

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many cases such as do not at the present pe
ceive the countenance of men of scienc
although we cannot subscribe to his views
proximate causes of some of the phenom
describes, yet we are gratified with the dis
his arguments,—the earnestness with which
forces them,—the solicitude that his pupil
rightly understand them,—and the candou
which he adverts to those other principles th
now so completely gained the ascendenc
those which he advocates.

It need not be supposed that the pupil, a
perusal of these Letters, will find a difficult
learning theories which are now explode
ordinary aid of a living instructer, or the p
a modern treatise on natural philosophy
precautions which the reader will find in
will easily rectify the judgment in its pr
causes; while the Letters of Euler,
they were for the benefit of a lady, will
the ingenuous mind to the love of sc
Nor is the evidence of piety he has
connexion with some of the highest
of philosophy one of the least inte
of these agreeable volumes.

AMERI

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PREFACE.

It has long been a reproach against English literature, that the composition of elementary and popular works has been left almost exclusively in the hands of inferior writers, who possess only a general and superficial knowledge of the subjects of which they treat. The influence of this practice upon the diffusion of general and correct knowledge has been deeply felt by those who are desirous of introducing a system of education which embraces a wider range than the ordinary routine of classical instruction. The popular writings of those who acquire a knowledge of science for the purpose of teaching it differ in the most essential manner from those of a philosopher who devotes himself to the task of perspicuous illustration. However correct may be the principles, and however copious the details of a compiled work, it must always be defective in the selection of its topics, in the clearness of its reasoning, in the generality of its views, and in the suitableness of its illustrations. A mind like that of EULER, which from its infancy has been devoted to the study of Nature, selects at once the prominent features of the science which it is proposed to explain; excludes all perplexing and extraneous facts, and combines under general views the important truths which it is the object of the pupil to seize and retain. The justness of this remark cannot fail to be admitted by those who read the following Letters, which may be justly characterized as the most popular work that ever was written, and as the production of the profoundest philosopher that ever wrote.

EULER's Letters to a German Princess were first made known in Europe by an edition published by the Marquis CONDORCET and M. LACROIX, who enriched it with a variety of notes, and whose opinion of the work for the purposes of public instructio may be acceptable to the English reader:—

"The Letters of EULER to a German Prince says M. CONDORCET, "have acquired over all E rope a celebrity to which the reputation of the thor, the choice and importance of the several subj and the clearness of elucidation justly entitle t They have deservedly been considered as a tre of science, adapted to the purposes of every co seminary of learning. They may be studied to advantage without much previous elementary knowledge; they convey accurate ideas respecting a variety of objects, highly interesting in themselves, or calculated to excite a laudable curiosity; they inspire a proper taste for the sciences, and for that sound philosophy which, supported by science, and never losing sight of her cautious, steady, methodical advances, runs no risk of perplexing or misleading the attentive student."

The English reader is indebted to the late Rev. Dr. HENRY HUNTER for the following translation, which has gone through two editions. In this third edition the translation has received very essential improvements. The plates have been re-engraved and much improved, and a life of the Author has been added, together with various notes, which, the editor trusts, will be both interesting and useful to the reader.

Independently of the great popularity of this work, it possesses a particular interest at the present time, in consequence of its containing a popular view of the doctrine, that light consists in the undulations of an ethereal medium, which is now generally adopted, in consequence of recent discoveries in optics.

EDINBURGH, 22*d* *July*, 1823.

THE LIFE OF EULER.

Leonard Euler, one of the most distinguished mathematicians of the 18th century, was the son of Paul Euler, and Margaret Brucker, and was born at Bâsle on the 15th of April, 1707.

His father, who had been instructed in mathematics by the celebrated James Bernoulli, became pastor of the village of Riechen, near Bâsle, in the year 1708; and as soon as his son had arrived at the proper age, he instilled into him a fondness for mathematical learning, although he had destined him for the study of theology. He was afterward sent to the university of Bâsle, where he was found worthy to receive lessons from John Bernoulli, who was at that time regarded as the first mathematician in Europe. The assiduity and amiable disposition of Euler soon gained him the particular esteem of that great master, and the friendship of his two sons, Daniel and Nicolas Bernoulli, who had already become the disciples and the rivals of their father. John Bernoulli even condescended to give him once every week a particular lesson, for the purpose of explaining the difficulties which he encountered in the course

of his studies. Euler had not the good fortune to enjoy long this inestimable advantage. In 1723, he received the degree of Master of Arts; and on this occasion he obtained great applause by the Latin discourse which he delivered, containing a comparison between the Newtonian and Cartesian philosophy. At the request of his father, he now began the study of theology; but his attachment to the mathematics was so strong, that his father at last consented to allow him to follow the bent of his own genius.

Nicolas and Daniel Bernoulli having, in 1725, accepted the invitation of Catherine I. to become members of the Academy of Sciences of St. Petersburg, promised at their departure to employ their influence to procure for Euler an appointment in that city. In the following year they announced that they had a situation in view for him, and strongly advised him to apply his mathematical knowledge to physiology. Euler immediately attended the lectures of the most eminent medical professors at Bâsle, and made rapid progress in the study of medicine. His attention, however, was still directed to his favourite pursuits, and he found leisure to compose a dissertation on the Nature and Propagation of Sound, and another on the Masting of Ships, which was written for the prize proposed by the Academy of Sciences in 1727. As this subject was actuall suggested by several members of the academy, wi the view of bringing into notice the talents of Bouguer, who had paid particular attention to t subject, and who was then professor of hydrograp in the seaport town of Croisic, it was not likely

Euler, who was destitute of all practical knowledge of naval affairs, should have succeeded in the competition. Bouguer, of course, carried off the first prize; but Euler obtained what is called the *accessit*, or second prize, an honour of no trivial magnitude, when we consider that he was then only twenty years of age. About this time Euler was a candidate for the vacant professorship of natural philosophy in the university of Bâsle; but he had not the good fortune to be elected.

Daniel and Nicolas Bernoulli used all their influence to procure an appointment for their young friend; and having at last succeeded, they requested him to repair immediately to St. Petersburg. Euler lost no time in obeying this welcome summons; but, after he had begun his journey, he had the mortification to learn that Nicolas Bernoulli had fallen a victim to the severity of the climate; and the very day upon which he entered the Russian territory was that of the death of the Empress Catherine I.; an event which at first threatened the dissolution of the academy, of which she had laid the foundation. Having reached St. Petersburg at this unfortunate period, Euler resolved to enter into the Russian navy, and had actually received the promise of a lieutenancy, and rapid promotion, from Admiral Sievers; but fortunately for geometry, a change took place in the aspect of public affairs in 1730, and Euler obtained the situation of Professor of Natural Philosophy. In 1733 he succeeded Daniel Bernoulli, when that illustrious mathematician retired into the country; and in the same year he married

Mademoiselle Gsell, a Swiss lady, and the daughter of a painter whom Peter the Great had carried into Russia upon his return from his first tour. In 1735, a very intricate problem having been proposed by the Academy of St. Petersburg, Euler completed the solution of it in three days; but the exertion of his mind had been so violent, that it threw him into a fever which endangered his life, and deprived him of the use of one of his eyes. In 1738, the Academy of Sciences at Paris crowned his memoir, entitled *Sur la Nature et les Proprietés du Feu;* and in 1740, he divided with Daniel Bernoulli, and our countryman Colin Maclaurin, the prize given by the same academy for the best dissertation on the flux and reflux of the sea. Daniel Bernoulli had treated the subject with a sagacity and method which characterized all his labours. The dissertation of Maclaurin contained his celebrated theorem on the equilibrium of elliptical spheroids; and that of Euler was marked with an improvement on the integral calculus, which seemed to resolve the fundamental equation of almost all the great problems on the motions of the heavenly bodies.

In consequence of an invitation from the King of Prussia, through his minister the Count de Mardefield, Euler quitted St. Petersburg and went to Berlin in the month of June, 1741. Upon his arrival, he was honoured with a letter from the king o Prussia, written from his camp at Reichenbach; an he was soon after presented to the queen-mother, princess who took great pleasure in the conversatio of illustrious men. She treated Euler with th utmost familiarity; but never being able to draw him into any conversation but that of monosyllables, she one day asked him why he did not wish to speak to her? "Madam," replied Euler, "it is because I have just come from a country where every person who speaks is hanged."

The memoirs and works with which Euler enriched mathematics and physics are so extremely numerous that it would occupy many pages to give even the briefest account of them. In many of his physical memoirs, Euler has been justly reproached for having applied the calculus to the most unfounded physical hypotheses, or to metaphysical principles which had not been sufficiently examined; and on this account several of his memoirs have no value whatever, except in so far as they exhibit fine specimens of the resources of analysis. His Dissertations on Windmills, on Achromatic Telescopes, on Naval Architecture, and on Gunnery are among the number of those which are liable to this criticism.

When Euler was at Berlin, the Princess of Anhalt Dessau, the niece of the King of Prussia, was desirous to receive from him some instruction in the different branches of natural philosophy; and for her use he drew up the present work, which was translated into most of the languages of Europe, and which has always been much esteemed, particularly for the singular perspicuity with which its author has explained some of the most profound truths in physics. The King of Prussia often employed Euler in calculations relative to the mint, and other objects of finance,—in the conducting of the waters of Sans

Souci, and in the examination of canals, and other public works.

In 1744, Euler was appointed Director of the Mathematical Class of the Academy, and in the same year he obtained the prize offered by the Academy of Sciences at Paris for the best work on the theory of magnetism.

About this time Robin's Treatise on Gunnery had appeared in England, and though our countryman had treated Euler with great severity, this act of injustice did not prevent him from recommending it to the King of Prussia as the best book on the subject. He even translated it, and in the additions which he made, he gave a complete theory of the motion of projectiles. M. Turgot ordered this work to be translated into French, and introduced into the schools of artillery; and about the same time there appeared a splendid edition of it in England.

In 1746, he published his new Theory of Ligh and Colours; and in 1759, his memoir *Sur les eff du Roulis et du Tangage*, gained the prize offer by the French Academy of Sciences.

In 1750, Euler went to Frankfort to receive mother, who was then a widow, and to conduct to Berlin, where she remained till the time of death, in 1761; having enjoyed for eleven years assiduous attention of a favourite son, and the pleasure of seeing him universally esteemed an mired.

When Euler remained at Berlin, he form intimate acquaintance with M. De Maupert learned President of the Prussian Acad

Sciences, and he defended Maupertuis's celebrated and favourite principle of the least action, by resolving, by means of it, some of the most difficult problems in mechanics. In the dispute into which he was thus led with Kœnig, who had attacked Maupertuis in 1751, he lost for a while his usual serenity, and became one of the enemies of that unfortunate individual.

Although the number of foreign associates in the French Academy of Sciences was limited to eight, yet Euler was appointed to the ninth place in 1755, on the condition that no appointment should take place at the first vacancy.

In the year 1760, the Russian army under General Tottleben penetrated into the March of Brandenburg, and pillaged a farm which Euler possessed near Charlottenberg. As soon as the Russian general was informed of the event, he immediately repaired the loss by a very large sum; and upon giving notice of the circumstance to the Empress Elizabeth, she added to this indemnity a present of four thousand florins. This act of generosity, no doubt, had a powerful effect in attaching Euler to the Russian government, which, in spite of his absence, had always paid him the pension which it granted him in 1742. Having received an invitation from the Empress Catherine, he obtained permission from the King of Prussia to return to St. Petersburg to spend the remainder of his days; but his eldest son was not allowed to accompany him. When Euler was on the eve of his departure, Prince Czartorisky invited him, in the name of the King of

Poland, to take the road of Warsaw, where, load with kindness, he spent ten days with Stanisla who afterward honoured him with his corresponden

Shortly after his arrival in St. Petersburg, on t 17th July, 1766, he lost the sight of his other ey having been for a considerable time obliged to pe form his calculations with large characters, trace with chalk upon a slate. His pupils and his chi dren copied his calculations, and wrote all his me moirs, while Euler dictated to them. To one of hi servants, who was quite ignorant of mathematica knowledge, he dictated his Elements of Algebra, a work of very great merit, which has been translated into English and many other languages. Euler now acquired the rare faculty of carrying on in his mind the most complicated analytical and arithmetical calculations; and M. d'Alembert, when he saw him at Berlin, was astonished at some examples of this kind which occurred in their conversation. With the design of instructing his grandchildren in the extraction of roots, he formed a table of the six first powers of all numbers, from 1 to 100, and he recollected them with the utmost accuracy. Two of his pupils having computed to the 17th term, a complicated converging series, their results differed one unit in the fiftieth cypher; and an appeal being made to Euler, he went over the calculation in his mind, and his decision was found correct.

His principal amusement, after he lost his sight, was to make artificial loadstones, and to give lessons on mathematics to one of his grandchildren, who seemed to evince a taste for the science.

In 1771, a dreadful fire broke out in St. Petersburg, and reached the house of Euler. Peter Grimm, a native of Bâsle, having learned the danger in which his illustrious countryman was placed, threw himself among the flames, and, reaching Euler's apartment, brought him off on his shoulders, at the risk of his life. His library, however, and his furniture were consumed; but, by the activity of Count Orloff, his MSS. were saved.

Having revised the lunar theory with the aid of his son, and his colleagues Krafft and Lexell, he constructed a set of new lunar tables, which appeared in 1772. These tables were, at the suggestion of Turgot, rewarded by the Board of Longitude in France; and when the more perfect tables of Mayer obtained the great premium of three thousand pounds offered by the British parliament, the sum of three hundred pounds was given to Euler for having furnished the theorems made use of by Mayer in his theory.

In the year 1773, Euler published, at St. Petersburg, his great work on the construction and management of vessels. A new edition soon afterward appeared at Paris, and at the desire of the French king it was introduced into the schools of marine, and a reward of 1000 rubles transmitted to the author, accompanied by a handsome letter from the celebrated Turgot. About the same time an Italian, an English, and a Russian translation of it appeared, and the Russian government presented Euler with a gift of 2000 rubles.

Three of Euler's memoirs on the Inequalities in the Motions of the Planets, were crowned by the

:h Academy of Sciences; and he also gained izes of 1770 and 1772, by his perfection of the theory.

ving lost his first wife, by whom he had thirchildren, eight of whom died in early life, he iarried a second time, in 1776, to Mademoiselle the aunt of his first wife.

ler underwent the operation of couching, which ittended with the happy result of restoring his but whether from the negligence of his suror from his being too eager to avail himself of w organs, he again lost his sight, and suffered severe pain from the relapse. His love for e, however, continued unabated, and in the of seven years he transmitted seventy memoirs Academy of St. Petersburg. On the 7th of mber, 1783, after having amused himself with ating upon a slate the laws of the ascensional n of balloons, which at that time occupied the ion of philosophers, he dined with his relation exell, and spoke of the planet Herschel, and calculations by which its orbit was determined. rt time afterward, he was amusing himself with f his grandchildren, when, on a sudden, his pipe om his hand, and he expired of an apoplectic , in the 79th year of his age.

ler left behind him three sons, having lost his ughters in the latter years of his life. Twentyt of thirty of his grandchildren were alive at ne of his death.

er a long life, so successfully devoted to the es, Euler's reputation was very widely extended. Besides being a foreign member of the Academy of Sciences at Paris, he was a Fellow of the Royal Society of London, and he had received from most of the princes of the north, with whom he was well acquainted, the most flattering marks of their esteem. When the Prince-royal of Prussia visited St. Petersburg, he anticipated the visit of Euler, and passed several hours at the bedside of this great man, holding him all the time by the hand, and having, at the same time, upon his knee one of Euler's grandchildren, who had displayed a premature attachment to geometry. The death of Euler was considered as a public loss even in the country where he lived; and the Academy of St. Petersburg decreed to him, at their own expense, a marble bust, which was placed in their public hall. In an allegorical picture which the academy had put up during his life, Geometry was represented as placed upon a basement covered with calculations. These calculations were the formulæ of Euler's Theory of the Lunar Motions.

Euler's knowledge was not limited to mathematics and the physical sciences. He had carefully studied anatomy, chymistry, and botany, and he was also deeply versed in ancient literature. He could repeat the Æneid from the beginning to the end, and he could even tell the first and last lines in every page of the edition which he used. In one of his works there is a learned memoir on a question in mechanics, of which, as he himself informs us, a verse of the Æneid gave him the first idea.

Euler possessed naturally a strong constitution;

and when we consider the nature of his studies, and the assiduity with which he pursued them, we cannot fail to be surprised at the great degree of health which he enjoyed. In all his habits he was sober and temperate,—in his manners unaffected and pleasing,—and in his temper lively and cheerful. In his moral and religious character there is much to admire. The high fame which he acquired, and the interruptions which he must have experienced, both at Berlin and St. Petersburg, never induced him to abandon the religious duties to which he had been educated. As long as he preserved his sight, he assembled the whole of his family every evening, and read a chapter of the Bible, which he accompanied with an exhortation. Theology was one of his favourite studies, and the doctrines which he held were the most rigid doctrines of Calvinism.

The following is a list of the principal works which Euler published in a separate form. His papers, which appeared in the Memoirs of the Academies of Berlin and St. Petersburg, are extremely numerous; and he left behind him no fewer than *two hundred* ready for publication, in order to fulfil a promise which he had made to Count Orloff, to supply memoirs for the *Acta Petropolitana* for twenty years after his death.

Dissertatio Physica de Sono. Basle, 1727.

Mechanica, sive motus scientia analytice exposita. Petropoli, 1736, 2 vols.

Tentamen novæ theoriæ musicæ. Petrop. 1739. This work contains many new views; but, as M. Fuss remarks, it had no great success, as it contained too much geometry for musicians, and too much music for geometers.

Methodus inveniendi lineas curvas maximi minimive proprietate gaudentes. Lausannæ, 1744, 4to.

Introductio in Analysin Infinitorum. Lausannæ, 1744, 2 vols. 4to. This work, which had become very scarce, was reprinted at Lyons in 1797. It was translated into French in 1796, by J. B. Labey, and published at Paris.

Theoria motuum planetarum et cometarum. Berolini, 1744.

Opuscula varii argumenti. Berolini, 1746, 1750, 1751, 3 vols. in 4to. The tables of the sun and moon, which are sometimes to be found separately, form part of the 1st volume of this collection. As the three volumes make only 600 pages, they are generally found in one.

Scientia navalis, seu tractatus de construendis ac dirigendis navibus. Petropoli, 1749, 2 vols. 4to.

Theoria motuum Lunæ exhibens omnes corporum inequalitates cum additamento. Berolini, 1753, 4to.

Dissertatio de principio minimæ actionis, una cum examine objectionum Cl. Koenigii, contra hoc principium factarum. Berolini, 1753, 4to.

Institutiones calculi differentialis, cum ejus usu in analysi infinitorum ac doctrina serierum. Berolini, 1755. Another edition of this work was published in 1787, in 2 vols. 4to, and another at St. Petersburg in 1804, in 2 vols. 4to.

Constructio lentium objectivarum ex duplici vitro. Petrop. 1762.

Meditationes de perturbatione motus cometarum ab attractione planetarum orta. Petrop. 1762, 4to.

Theoria motus corporum solidorum seu rigidorum. Rostochii, 1765, 4to.

Institutiones Calculi Integralis. Petrop. 1768–1770, 3 vols. 4to. Another edition, more correct, was published at St. Petersburg in 1792 and 1794, in 4 vols. 4to.

Dioptrica. Petrop. 1769, 1771, 3 vols. 4to.

Novæ Tabulæ Lunares singulari methodo constructæ. Petrop. 1772, 8vo.

Opuscula Analytica. Petrop. 1783, 1785, 2 vols. 4to.

Lettres à une Princesse d'Allemagne sur quelques sujets de Physique et de Philosophie. St. Petersburg, 1768, 1772, 3 vols. 8vo. Another edition was published at Berne in 1778, in 3 vols. 8vo. Another edition was published at Paris with notes by Condorcet, and another in 1812, by J. B. Labey.

Elemens d'Algèbre, trad. de l'Allemand, par J. Bernoulli, avec des notes par Lagrange et Garnier. Paris, 1807, 2 vols. 8vo. Two editions of this work were published at Lyons in 1774 and 1796, and an edition appeared in London translated into English.

Theorie complete de la construction et de la manœuvre des vaisseaux (le style retouché par Keralio). Paris, 1776, 8vo. The original edition of this work appeared at St. Petersburg in 1773.

A collection of the best productions of Euler appeared at Brienne in 1797, in 18 volumes.

A more extended list of the writings of this illustrious mathematician will be found in his Eulogé by Nicholas Fuss, which was published at St. Petersburg, in 1783, in 4to.

LETTERS
ON
DIFFERENT SUBJECTS
IN
NATURAL PHILOSOPHY.

LETTER I.

Of Magnitude, or Extension.

The hope of having the honour to communicate in person to your highness my lessons in geometry becoming more and more distant, which is a very sensible mortification to me, I feel myself impelled to supply personal instruction by writing, as far as the nature of the subjects will permit.

I begin my attempt by assisting you to form a just idea of *Magnitude;* producing, as examples, the smallest as well as the greatest extensions of matter actually discoverable in the system of the universe. And, first, it is necessary to fix on some one determinate division of measure, obvious to the senses, and of which we have an exact idea, that of a *foot,* for instance. The quantity of this once established, and rendered familiar to the eye, will enable us to form the idea of every other quantity as to length, great or small; the former, by ascertaining how many feet it contains, and the latter, by ascertaining what part of a foot measures it. For having the idea of a *foot*, we have that also of its *half*, of its *quarte* of its *twelfth part*, denominated an inch, of its *hundredth*, and of its *thousandth* part, which is so small as almost to escape the sight. But it is to be remarked, that there are animals not of greater extension than this last subdivision of a foot, which, however, are composed of members through which the blood circulates, and which again contain other animals, as diminutive compared to them as they are compared to us. Hence it may be concluded, that animals exist whose smallness eludes the imagination: and that these again are divisible into parts inconceivably smaller. Thus, for example, though the ten thousandth part of a foot be too small for sight, and, compared to us, ceases to be an object of sense, it nevertheless surpasses in magnitude certain complete animals, and must to one of those animals, were it endowed with the power of perception, appear extremely great.

Let us now make the transition from these minute quantities, in pursuing which the mind is lost, to those of the greatest magnitude. You have the idea of a mile; the distance from hence to Magdeburg is computed to be 83 English miles; a mile contains 5280 feet, and we employ it in measuring the distance of the different regions of the globe, in order to avoid numbers inconceivably great in our calculations, which must be the case if we used a foot instead of a mile. A mile then containing 5280 feet, when it is said that Magdeburg is 83 miles from Berlin, the idea is much clearer than if the distance of these two cities were said to be 438,240 feet: a number so great almost overwhelms the understanding. Again, we shall have a tolerably just idea of the magnitude of the earth, when we are told that its circumference is about 25,020 miles. And the diameter being a straight line passing through the centre, and terminating in opposite directions, in the surface of the sphere, which is the acknowledged figure of the earth,

for which reason also we give it the name of *globe*—the diameter of this *globe* is calculated to be 7964 miles; and this is the measurement which we employ for determining the greatest distances discoverable in the heavens. Of all the heavenly bodies the *Moon* is nearest to us, being distant only about 30 diameters of the earth, which amount to 240,000 miles, or 1,238,400,000 feet; but the first computation of 30 diameters of the earth is the clearest idea. The *Sun* is about 400 times farther from us than the moon, and when we say his distance is 12,000 diameters of the earth, we have a much clearer idea than if it were expressed in miles or in feet.

You know that the earth performs a revolution round the sun in the space of a year, but that the sun remains fixed. Besides the *Earth*, there are ten other similar bodies, named planets, which revolve round the sun; two of them at smaller distances, *Mercury* and *Venus;* and eight at greater distances, namely, *Mars*, *Ceres*, *Pallas*, *Juno*, *Vesta*, *Jupiter*, *Saturn*, and the *Georgium Sidus*. All the other stars which we see, comets excepted, are called fixed; and their distance from us is incomparably greater than that of the sun. Their distances are undoubtedly very unequal, which is the reason that some of these bodies appear greater than others. But the nearest of them is, unquestionably, above 5000 times more distant than the sun: its distance from us, accordingly, exceeds 45,000,000 of times the earth's diameter, that is, 356,050,000,000 miles; and this again, multiplied by 5280, will give that prodigious distance expressed in feet. And this, after all, is the distance only of those fixed stars which are the nearest to us;—the most remote which we see are perhaps a hundred times farther off.* It is probable, at the same time, that all these stars taken together constitute only a very small part of the whole universe, relatively to which these prodigious distance are not greater than a grain of sand compared to th earth. This immensity is the work of the Almighty who governs the greatest bodies and the smallest.

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* The author might have said millions instead of hundreds.—*American Editor.*

Berlin, 19th April, 1760.

LETTER II.

Of Velocity.

Flattering myself that your highness may be pleased to accept the continuation of my instructions, a specimen of which I took the liberty of presenting to you in a former letter, I proceed to unfold the idea of velocity, which is a particular species of extension, and susceptible of increase and of diminution. When any substance is transported, that is, when it passes from one place to another, we ascribe to it a velocity. Let two persons, the one on horseback, the other on foot, proceed from Berlin to Magdeburg, we have, in both cases, the idea of a certain velocity; but it will be immediately affirmed, that the velocity of the former exceeds that of the latter. The question then is, Wherein consists the difference which we observe between these several degrees of velocity? The road is the same to him who rides and to him who walks; but the difference evidently lies in the time which each employs in performing the same course. The velocity of the horseman is the greater of the two, as he employs less time on the road from Berlin to Magdeburg; and the velocity of the other is less, because he employs more time in travelling the same distance. Hence it is clear, that in order to form an accurate idea of velocity, we must attend at once to two kinds of quantity—namely, to the length of the road, and to the time employed. A body, therefore, which in the same time passes through double the space which another body does, has double its velocity; if in the same

time it passes through thrice the distance, it is said to have thrice the velocity, and so on. We shall comprehend, then, the velocity of a body, when we are informed of the space through which it passes in a certain quantity of time. In order to know the velocity of my pace, when I walk to Lytzow (about a league from Berlin), I have observed that I make 120 steps in a minute, and one of my steps is equal to two feet and a half. My velocity, then, is such as to carry me 300 feet in a minute, and a space 60 times greater, or 18,000 feet in an hour. Were I, therefore, to walk from hence to Magdeburg, it would take exactly 24 hours. This conveys an accurate idea of the velocity with which I am able to walk. Now it is easy to comprehend what is meant by a greater or less velocity. For if a courier were to go from hence to Magdeburg in 12 hours, his velocity would be the double of mine; if he went in eight hours, his velocity would be triple. We remark a very great difference in the degrees of velocity. The tortoise furnishes an example of a velocity extremely small. If she advances only one foot in a minute, her velocity is 300 times less than mine, for I advance 300 feet in the same time. We are likewise acquainted with velocities much greater. That of the wind admits of great variation. A moderate wind goes at the rate of 10 feet in a second, or 600 feet in a minute; its velocity therefore is the double of mine. A wind that runs 20 feet in a second, or 1200 in a minute, is rather strong; and a wind which flies at the rate of 50 feet in a second is extremely violent, though its velocity is only ten times greater than mine, and would take two hours and twenty-four minutes to blow from hence to Magdeburg.*

The velocity of sound comes next, which moves 1142 feet in a second, and 68,520 in a minute. This velocity, therefore, is 228 times greater than that of

* This estimate of the velocity of wind is too low. A *stiff breeze* will carry a balloon 150 miles in an hour, or 220 feet in a second.—*American Editor.*

my pace; and were a cannon to be fired at Magdeburg, if the report could be heard at Berlin, it would arrive there in seven minutes. A cannon-ball moves with nearly the same velocity; but when the piece is loaded to the utmost, the ball is supposed capable of flying 2000 feet in a second, or 120,000 in a minute. This velocity appears prodigious, though it is only 400 times greater than that of my pace in walking to Lytzow; it is at the same time the greatest velocity known upon earth. But there are in the heavens velocities far greater, though their motion appears to be extremely deliberate. You know that the earth turns round on its axis in 24 hours: every point of its surface, then, under the equator, moves 25,020 English miles in 24 hours, while I am able to get through only 83 miles. Its velocity is accordingly above 300 times greater than mine, and less notwithstanding than the greatest possible velocity of a cannon-ball. The earth performs its revolution round the sun in the space of a year, proceeding at the rate of 589,950 English miles in 24 hours. Its velocity, therefore, is 18 times more rapid than that of a cannon-ball. The greatest velocity of which we have any knowledge is undoubtedly that of light, which moves 12,000,000 English miles every minute, and exceeds the velocity of a cannon-ball 400,000 times.

22d April, 1760.

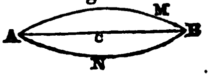
LETTER III.

Of Sound, and its Velocity.

The elucidations of the different degrees of velocity, which I have had the honour to lay before you, carry me forward to the examination of sound, or noise in general. It must be remarked, that a certain portion of time always intervenes before sound can reach our ears, and that this time is longer in proportion to our distance from the place where the sound is produced; a second of time being requisite to convey sound 1142 feet.

When a cannon is fired, those who are at a distance do not hear the report for some time after they have seen the flash. Those who are about five miles off, or 26,400 feet distant, do not hear the report till 23 seconds after they see the flash. You must no doubt have frequently remarked, that the noise of thunder does not reach the ear for some time after the lightning; and it is by this we are enabled to calculate our distance from the place where the thunder is generated. If, for example, we observe that 20 seconds intervene between the flash and the thunder-clap, we may conclude that the seat of the thunder is 22,840 feet distant, allowing 1142 feet of distance for every second of time. This primary property leads us to inquire in what sound consists. Whether its nature is similar to that of smell—that is, whether sound issues from the body which produces it, as smell is emitted from the flower, by filling the air with subtile exhalations, calculated to affect our sense of smelling. This opinion was formerly entertained; but it is now demonstrated, that from a bell struck nothing proceeds that is conveyed to our ear, and that the body which produces sound loses no part of its substance. When we look upon a bell that is struck, or the string of an instrument when touched, we perceive that these bodies are then in a state of trembling, or agitation, by which all their parts are affected; and that all bodies susceptible of such an agitation of their parts likewise produce sound. These shakings or vibrations are visible in the string of an instrument when it is not too small; the tense string A C B passes alternatively into the situation of A M B and A N B., *Fig.* 1., *in which I have represented these vibrations*

Fig. 1.



much more obvious to sense than they are in fact. It must be observed, that these vibrations put the adjacent air into a similar vibration, which is successively communicated to the more remote parts of the air, till it come at length to strike our organ of hearing. It is the air, then, which receives these vibrations, and which transmits the sound to our ear. Hence it is evident, that the perception of sound is nothing else but the impression made on our ear by the concussion of the air, communicated to us through the organ of hearing; and when we hear the sound of a string touched, our ear receives from the air as many strokes as the string performs vibrations in the same time. Thus, if the string performs 100 vibrations in a second, the ear likewise receives 100 strokes in the same time; and the perception of these strokes is what we call sound. When these strokes succeed each other uniformly, or when their intervals are all equal, the sound is regular, and such as is requisite to music. But when the strokes succeed unequally, or when their intervals are unequal among themselves, an irregular noise, incompatible with music, is the result. On considering somewhat more attentively the musical sounds, whose vibrations take place equally, I remark first, that when the vibrations, as well as the strokes impressed on the ear are more or less strong, no other difference of sound results from it but that of stronger or weaker, which produces the distinction termed by musicians, *forte et piano.* But there is a difference much more essential when the vibrations are more or less rapid—that is, when more or fewer of them are performed in a second. When one string makes 100 vibrations in a second, and another string makes 200 vibrations in the same time, their sounds are essentially different; the former is lower or more flat, and the other higher or more sharp Such is the real difference between the flat an sharp sounds, on which all music hinges, and whic

teaches how to combine sounds different in respect of flatness and sharpness, but in such a manner as to produce an agreeable harmony. In the flat sounds there are fewer vibrations in the same time than in the sharp sounds; and every key of the harpsichord contains a certain and determinate number of vibrations which are completed in a second. Thus the note marked by the letter C makes nearly 100 vibrations in a second, and the note marked $\overline{\overline{\overline{\overline{c}}}}$ makes 1600 vibrations in the same space of time. A string which vibrates 100 times in a second will give precisely the note C; and if it vibrated only 50 times, the note would be lower or more flat. But with regard to our ear, there are certain limits beyond which sound is no longer perceptible. It would appear that we are incapable of determining either the sound of a string which makes less than 30 vibrations in a second, because it is too low; or that of a string which would make more than 7552 in a second, because such a note would be too high.*

26th April, 1760.

LETTER IV.

Of Consonance and Dissonance.

I RESUME my remark, that on hearing a simple musical sound, our ear is struck with a series of strokes equally distant from each other, the frequency and number of which, in a given space of time, constitute the difference which subsists between low notes and high; so that the smaller the number of vibrations or strokes produced in a given time, say a second, the lower we estimate that note; and the greater the number of such vibrations, the higher is the note. The perception of a simple musical sound may, therefore, be compared to a series of dots equidistant from each other, as . . . . . If the intervals between these dots be greater or smaller, the sound produced will be lower or higher. It cannot be doubted, that the perception of a simple sound is somewhat similar or analogous to the sight of such a series of dots equidistant from each other: we are enabled thus to represent to the eye what the ear perceives on hearing sound. If the distances between the dots were not equal, or were these dots scattered about confusedly, they would be a representation of a confused noise, inconsistent with harmony. This being laid down, let us consider what effect two sounds emitted at once must produce on the ear. First, it is evident, that if two sounds are equal, or if each performs the same number of vibrations in the same time, the ear will be affected in the very same manner as by a single note; and in music these two notes are said to be in unison, which is the simplest *accord:* we mean by the term *accord* the blending of two or more sounds heard at once. But if two sounds differ in respect of low and high, we shall perceive a mixture of two series of strokes, in each of which the intervals are equal among themselves, but greater in the one than in the other; the greater intervals corresponding to the lower note, and the smaller to the higher. This mixture, or this accord of two notes, may be represented to the eye by two series of dots arranged on two lines A B and C D:

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* It is highly probable that there are sounds which from their extreme lowness are quite inaudible to human ears, but which may nevertheless serve as the medium of intelligence to inferior animals.—*Am. Editor.*

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     1    2    3    4    5    6    7    8    9   10   11
A    .    .    .    .    .    .    .    .    .    .    .     B
C    .   .   .   .   .   .   .   .   .   .   .   .         D
     1   2   3   4   5   6   7   8   9   10  11  12
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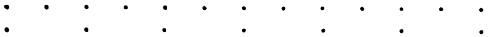
and in order to form a just idea of these two series, we must have a clear perception of the order which subsists among them; or, in other words, of the relation between the intervals of the one line and of the

other. Having numbered and marked the dots of each line, and placed No. 1 under No. 1, those marked with the figure 2 will not exactly correspond, and still less those marked 3: but we find No. 11 exactly over No. 12; from which we discover that the higher note makes 12 vibrations, and the other only 11. If we had not affixed the figures, the eye would hardly have perceived this order: it is the same with the ear, which would with much difficulty have traced it in the two notes which I have represented by two rows of dots. But in the following figure,



you discover at the first glance that the upper line contains twice as many dots as the under, or that the intervals in the under line are twice as great as those of the upper. This is undoubtedly, next to unison, the simplest of all cases in which you can at once discover the order which subsists between these two series of dots; and the same thing holds with respect to the two notes represented by these two lines of dots; the number of vibrations contained in the one will be precisely the double of the vibrations contained in the other, and the ear will easily perceive the pleasing relation of these two sounds; whereas, in the preceding case, it was extremely difficult, if not impossible, to discriminate. When the ear readily discovers the relation subsisting between two notes, their accord is denominated *consonance;* and if it be very difficult, or even impossible to catch this relation, the accord is termed *dissonance*. The simplest consonance, then, is that in which the high note produces precisely twice as many vibrations as the low note. This consonance, in the language of music, is called *octave*—every one knows what it means; and two notes which differ precisely an octave harmonize so perfectly, and possess such a complete resemblance, that musicians mark them by the same letters. Hence it is that in church-music the women sing an octave higher than the men, and yet imagine they are uttering the same sounds. You may easily ascertain the truth of this by touching the keys of a harpsichord, when you will perceive with pleasure the delightful accord of all the notes which are just an octave distant; whereas any other two notes whatever will strike the ear less agreeably.

29th April, 1760.

LETTER V.

Of Unison and Octaves.

You have by this time remarked, that the accord which musicians call an *octave* strikes the ear in a manner so decided, that the slightest deviation is easily perceptible. Thus, having touched the key marked F, that marked f, which is an octave higher, is easily attuned to it, by the judgment of the ear only. If the string which is to produce this note be ever so little too high or too low, the ear is instantly offended; and nothing is easier than to put the two keys perfectly in tune. Thus we observe, that in singing the voice slides easily from one note to another, which is just an octave higher or lower. But were it required to pass immediately from the note F to the note d, for example, an ordinary singer might easily fall into a mistake, unless assisted by an instrument. Having fixed the note F, it is almost impossible all at once to make the transition to the note d. What then is the reason of this difference, that it is so easy to make note f harmonize with note F, and so difficult to make note d accord with it? The reason is evident from the remarks already made: It is this, that note F and note f make an octave, and that the number of vibrations of note f is precisely double that of note F. In order to have the perception of this accord, you have only to consider the proportion of one to two, which, as it instantly strikes the eye by the representation of the dots I formerly employed, affects the ear in a similar manner. You will easily comprehend, then, that the more simple any proportion is, or expressed by small numbers, the more distinctly it presents itself to the understanding, and conveys to it a sentiment of satisfaction. Architects likewise carefully attend to this maxim, as they uniformly employ in their works proportions as simple as circumstances permit. They usually make the height of doors and windows double the breadth, and endeavour to employ throughout proportions capable of being expressed by small numbers, because this is obvious and grateful to the understanding. The same thing holds good in music: accords are pleasing only in so far as the mind perceives the relation subsisting between the sounds; and this relation is so much more easily perceptible as it is expressed by small numbers. Now, next to the relation of equality, which denotes two sounds in unison, the ratio of two to one is undoubtedly the most simple, and it is this which furnishes the accord of an octave: hence it is evident, that this accord possesses many advantages above every other consonance. Having thus explained the accord, or interval of two notes denominated by musicians an octave, let us consider several notes, as F, f, $\bar{f}$, $\bar{\bar{f}}$ $\bar{\bar{\bar{f}}}$, each of which is an octave higher than the one immediately preceding: since then the interval of F from f, of f from $\bar{f}$, of $\bar{f}$ from $\bar{\bar{f}}$, of $\bar{\bar{f}}$ from $\bar{\bar{\bar{f}}}$ is an octave, the interval of F to $\bar{f}$ will be a double octave, that of F to $\bar{\bar{f}}$ a triple octave, and that of F to $\bar{\bar{\bar{f}}}$ a quadruple octave. Now, while note F makes one vibration, note f makes two, note $\bar{f}$ makes four, note $\bar{\bar{f}}$ makes eight, and note $\bar{\bar{\bar{f}}}$ makes sixteen: hence we see, that as an octave corresponds in the relation of 1 to 2, a double octave must be in the ratio of 1 to 4, a triple in that of 1 to 8, and a quadruple in that of 1 to 16. And the ratio of 1 to 4 not being so simple as that of 1 to 2, for it does not so readily strike the eye, a double octave is not so easily perceptible to the ear as a single; a triple is still less perceptible, and a quadruple still much less so. When, therefore, in tuning a harpsichord, you have fixed the note F, it is not so easy to attune the double octave $\bar{f}$ as the single f; it is still more difficult to attune the triple octave $\bar{\bar{f}}$ and the quadruple $\bar{\bar{\bar{f}}}$ without rising through the intermediate octaves. These accords are likewise comprehended in the term consonance; and as that of unison is most simple, they may be arranged according to the following gradations:—

I. Degree, unison, indicated by the relation of 1 to 1.
II. Degree, the immediate octave, in the ratio of 1 to 2.
III. Degree, the double octave, in that of 1 to 4.
IV. Degree, the triple octave, in that of 1 to 8.
V. Degree, the quadruple octave, in that of 1 to 16.
VI. Degree, the quintuple octave, in that of 1 to 32.

And so on as long as sound is perceptible. Such are the accords denominated consonances, to the knowledge of which we have been thus far conducted; but hitherto we know nothing of the other species of consonance, and still less of the dissonances employed in music. Before I proceed to the explanation of these, I must add one remark respecting the name *octave*, given to the interval of two notes, the one of which contains twice the vibrations contained in the other. You see the reason of it in the principal stops of the harpsichord, which rise by seven degrees before you arrive at the octave C, D, E, F, G, A, B, c, so that stop c is the eighth, reckoning C the first. And this division depends on a certain series of musical intervals, the nature of which shall be unfolded in the following Letters.

3d May, 1760.

LETTER VI.

Of other Consonances.

It may be affirmed, that the relations of 1 to 2, of 1 to 4, of 1 to 8, of 1 to 16, which we have hitherto considered, and which contain the progression of octaves, are all formed by the number 2 only; since 4 is 2 times 2; 8, 2 times 4; 16, 2 times 8. Were we to admit, therefore, the number 2 alone into music, we should arrive at the knowledge of only the accords or consonances, which musicians call the single, double, or triple octave; and as the number 2, by its redublication, furnishes only the numbers 4, 8, 16, 32, 64, the one being always double the preceding, all other numbers would remain unknown. Now, did an instrument contain octaves only, as the notes marked C, c, $\bar{c}$, $\bar{\bar{c}}$, $\bar{\bar{\bar{c}}}$, and were all others excluded, it could not produce an agreeable music, on account of its too great simplicity. Let us introduce, then, together with number 2, the number 3 likewise, and observe what accords or consonances would be the result. The ratio of 1 to 3 presents at once two sounds, the one of which makes 3 times more vibrations than the other in the same time. This ratio is undoubtedly the most easily to be comprehended, next to that of 1 to 2; it will, accordingly, furnish very pleasing consonances, but of a nature totally different from that of octaves. Let us suppose, then, that in the proportion of 1 to 3, number 1 corresponds to note C; since note c is expressed by number 2, number 3 gives a sound higher than c, but at the same time lower than note $\bar{c}$ which corresponds to number 4. Now, the note expressed by 3 is that to which musicians affix the letter g, and they denominate the interval from c to g, *a fifth*, because in the keys of a harpsichord that of g is the fifth from c, as c, d, e, f, g. If then number duces the sound C, number 2 will give c; n 3 gives g, number 4 the note $\bar{\bar{c}}$; and note $\bar{g}$ be the octave of g, the number corresponding to it w be 2 times 3, or 6. Rising still an octave, the sou $\bar{\bar{g}}$ will correspond to a number twice greater, that 12. All the notes with which the two numbers and 3 furnish us, indicating note C by 1, therefore, an

C, c, g, $\bar{c}$, $\bar{g}$, $\bar{\bar{c}}$, $\bar{\bar{g}}$, $\bar{\bar{\bar{c}}}$
1, 2, 3, 4, 6, 8, 12, 16.

Hence it is clear, that the ratio of 1 to 3 expresses an interval compounded of an octave and a fifth; and that this interval, on account of the simplicity of the numbers which represent it, must be, next to the octave, the most grateful to the ear. Musicians accordingly assign the second rank among consonances to the fifth; and the ear catches it so easily, that there is no difficulty in tuning a fifth. For this reason, in violins, the four strings rise by fifths, the lowest being g, the second $\bar{d}$, the third $\bar{a}$, and the fourth $\bar{\bar{e}}$;* and every musician puts them in tune by the ear only. A fifth, however, is not so easily tuned as an octave; but the fifth above the octave, as from C to g, being expressed by the proportion of 1 to 3, is more perceptible than a simple fifth, as from C to G, or from c to g, which is expressed by the proportion of 2 to 3: and it is likewise known by experience, that having fixed the note C, it is easier to attune to it the higher fifth g than the simple G. If unity had marked the note F, number 3 would mark the note $\bar{c}$, so that

F, f, $\bar{c}$, $\bar{f}$, $\bar{\bar{c}}$, $\bar{\bar{f}}$, $\bar{\bar{\bar{c}}}$ would be marked by
1, 2, 3, 4, 6, 8, 12, where, from f to $\bar{c}$ the interval is a fifth, in the relation of 2 to 3; from $\bar{f}$ to $\bar{\bar{c}}$, from $\bar{\bar{f}}$ to $\bar{\bar{\bar{c}}}$ are also fifths, as the ratio of 4 to 6, and of 8 to 12, is the same as that of 2 to 3. For if two strings perform, in the same time, the one 4 vibrations, the other 6, the former string will make, in a

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* That is, in the language of *sol-faing*, *sol*, *re*, *la*, *mi*.

time equal to half the first space of time, two vibrations; and the second, in the same time, will make three. Now the sounds emitted from these strings are the same in both cases; of consequence, the relation of 4 to 6 expresses the same interval as that of 2 to 3, that is, a fifth. Hence we have arrived at the knowledge of another interval contained in the ratio of 3 to 4, which is that of $\bar{c}$ to $\bar{f}$; and consequently also, of c to f, or of C to F. Musicians call it a *fourth;* and being expressed by greater numbers, it is not so agreeable, by a great deal, as the fifth, and still less so than the octave. Number 3 having furnished us new accords or consonances, namely, the fifth and the fourth, before we call in any others, let us take it again three times, in order to have the number 9, which will give a higher note than note 3, or $\bar{c}$ one octave and one fifth. Now, $\bar{\bar{c}}$ is the octave of $\bar{c}$, and $\bar{\bar{g}}$ the fifth of $\bar{\bar{c}}$; number 9 then gives the note $\bar{\bar{g}}$, so that $\bar{\bar{c}}$, $\bar{\bar{f}}$, $\bar{\bar{g}}$, $\bar{\bar{\bar{c}}}$ will be marked by 6, 8, 9, 12; and if these notes be taken in the lower octaves, the relations remaining the same, we shall have,

C, F, G; c, f, g; $\bar{c}$, $\bar{f}$, $\bar{g}$; $\bar{\bar{c}}$, $\bar{\bar{f}}$, $\bar{\bar{g}}$; $\bar{\bar{\bar{c}}}$,
6, 8, 9; 12, 16, 18; 24, 32, 36; 48, 64, 72; 96;

which leads us to the knowledge of new intervals.

The first is that of F to G, contained in the ratio of 8 to 9, which musicians call a *second*, or *tone*. The second is that of G to f, contained in the ratio of 9 to 16, called a *seventh;* and which is one second, or one tone less than an octave. These proportions, being already expressed by very great numbers, are not reckoned among the consonances; and musicians call them *dissonances* or *discords*.

Again, if we take three times the number 9, or 27, it will mark a tone higher than $\bar{c}$, and precisely a fifth higher than g; it will be accordingly the tone $\bar{d}$, and its octave $\bar{\bar{d}}$ will correspond to twice the number 27, or 54, and its double octave $\bar{\bar{\bar{d}}}$ to twice the number 54, or 108. Let us represent these to some octaves lower, in the manner following:

C, D, F, G; c, d, f, g; $\bar{c}$, $\bar{d}$,
24, 27, 32, 36; 48, 54, 64, 72; 96, 108, 1
$\bar{g}$; $\bar{\bar{c}}$, $\bar{\bar{d}}$, $\bar{\bar{f}}$, $\bar{\bar{g}}$; $\bar{\bar{\bar{c}}}$.
144; 192, 216, 256, 288; 384.

Hence we see, that the interval from D to F contained in the ratio 27 to 32, and that of F to d the ratio of 32 to 54, the two terms of which ar divisible by 2; and then, in place of this relation we have that of 16 to 27. The first interval is calle a *tierce minor*, or *lesser third*, and the other a *greater sixth*. The number 27 might be still further multiplied by 3; but music extends not so far, and we limit ourselves to number 27, resulting from 3 multiplied three times by itself: other musical tones still wanting are introduced by means of number 5, and shall be explained in my next Letter.

3d May, 1760.

LETTER VII.

Of the Twelve Tones of the Harpsichord.

The present subject of my correspondence with your highness is so dry, that I begin to apprehend it may be growing tiresome. That I may not waste too much time on it, and be relieved from the necessity of recurring frequently to a topic so uninteresting, I send you by this conveyance three Letters at once. My intention in undertaking it was to render visible the real origin of musical notes, with which musicians themselves are almost totally unacquainted. It is not to theory they are indebted for the knowledge of all these sounds, but rather to the secret power of genuine harmony, operating so efficaciously on their ears, that they have been con-

strained, if I may be allowed to say it, to receive tones actually in use, though they are not hitherto perfectly agreed respecting their just determination. The principles of harmony are ultimately reducible to numbers, as I have demonstrated; and it has been remarked, that the number 2 furnishes octaves only, so that having fixed, for example, the note F, we are conducted to the notes f, $\bar{f}$ $\bar{\bar{f}}$ $\bar{\bar{\bar{f}}}$. The number 3 afterward furnishes C, c, $\bar{c}$ $\bar{\bar{c}}$ $\bar{\bar{\bar{c}}}$, which differ one fifth from the preceding series; and the repetition of this same number 3 furnishes again the fifths of the first, namely, G, g, $\bar{g}$ $\bar{\bar{g}}$ $\bar{\bar{\bar{g}}}$; and finally, the third repetition of this number 3 adds further the notes D, d, $\bar{d}$ $\bar{\bar{d}}$ $\bar{\bar{\bar{d}}}$. The principles of harmony then, being attached to simplicity, seem to forbid our pushing farther the repetition of number 3; hitherto, accordingly, we have only the following notes to each octave:
F, G, c, d, f,
16, 18, 24, 27, 32; which certainly would not furnish a very copious music. But let us introduce, in addition to these, number 5, and observe the tone which shall emit five vibrations while F emits only one. Now f makes two vibrations in the same time $\bar{f}$ makes four, and $\bar{\bar{c}}$ six. The note in question, then, is between $\bar{f}$ and $\bar{\bar{c}}$. It is that which musicians indicate by letter $\bar{a}$, the accord of which with note $\bar{f}$ is denominated a *greater third*, and is found to produce a very agreeable concord, being expressed by the very simple ratio of 4 to 5. Further, note $\bar{a}$ with note $\bar{\bar{c}}$ produces an accord contained in the ratio of 5 to 6, which is almost as agreeable as the former, and which is denominated a *lesser third*, represented by the ratio of 27 to 32, and its difference from the first is almost imperceptible to the ear. This same number 5 being applied to the other notes, G, c, d, will give us, in like manner, their greater thirds, taken in the second octave below, that is to say, the notes $\bar{b}$ $\bar{\bar{e}}$ and $\bar{\bar{\bar{f}}}$, which, being transposed, will give

the following notes, with their corresponding numbers:

F,	Fs,	G,	A,	B,	c,	d,	e,	f.
128,	135,	144,	160,	180,	192,	216,	240,	256.

Take away the notes Fs, and you will have the principal touches of the harpsichord, which, according to the ancients, constitute the genus denominated *diatonic*, resulting from number 2, from number 3, thrice repeated, and from number 5. Admitting these sounds only, we are in a condition to compose harmonies very agreeable and various, the beauty of which is founded on the simplicity alone of the numbers corresponding to the notes. Finally, upon applying a second time the number 5, we shall be furnished with the thirds of the four new tones, A, E, B, Fs, which we have just found, we shall have the notes, Cs, Gs, Ds, and B, so that now the octave is completed of the 12 tones received in music. All these tones derive their origin from the three numbers 2, 3, and 5, multiplying 2 by itself, as often as the octaves require; but we carry the multiplication of 3 only to the third stage, and of 5 to the second. All the tones of the first octave are contained in the following table, in which you will see how the fundamental numbers, 2, 3, and 5, enter into the composition of those which express the relation of these notes.

ut or	C	2, 2, 2, 2, 2, 2, 2, 3 . . .	384	Differences.
ut ♯	Cs	2, 2, 2, 2, 5, 5	400	16
re	D	2, 2, 2, 2, 3, 3, 3	432	32
re ♯	Ds	2, 3, 3, 5, 5	450	18
mi	E	2, 2, 2, 2, 2, 3, 5	480	30
fa	F	2, 2, 2, 2, 2, 2, 2, 2, 2 . .	512	32
fa ♯	Fs	2, 2, 3, 3, 3, 5	540	28
sol	G	2, 2, 2, 2, 2, 2, 3, 3 . . .	576	36
sol ♯	Gs	2, 2, 2, 3, 5, 5	600	24
la	A	2, 2, 2, 2, 2, 2, 2, 5 . . .	640	40
si b.	B♭	3, 3, 3, 5, 5	675	35
si n	B♮	2, 2, 2, 2, 3, 3, 5	720	45
ut	c	2, 2, 2, 2, 2, 2, 2, 3, 3 . .	768	48

While note C makes 384 vibrations, the tone Cs gives 400, and the others as many as are marked by their corresponding numbers: note c will give, then, in the same time, double the number of vibrations marked by 384, that is 768. And for the following octaves, you have only to multiply these numbers by 2, by 4, or by 8. Accordingly, note $\bar{c}$ will give twice 768, or 1536 vibrations; note $\bar{\bar{c}}$ twice 1536, or 3072 vibrations; and note $\bar{\bar{\bar{c}}}$ twice 3072, or 6144 vibrations. In order to comprehend the formation of sounds by means of these numbers 2, 3, and 5, it must be remarked, that the points placed between the numbers in the preceding number signify that they are multiplied into each other; thus, taking the tone Fs, for example, the expression 2, 2, 3, 3, 3, 5, signifies 2 multiplied by 2, that product by 3, that again by 3, that again by 3, and that by 5. Now 2 by 2 make 4, that by 3 make 12, that by 3 make 36, that by 3 make 108, and that by 5 make 540. Hence it is seen that the differences between these tones are not equal among themselves; but that some are greater, and others less. This is what real harmony requires. The inequality, however, not being considerable, we commonly look on all these differences as equal, denominating the interval from one note to another *semitone;* and thus the octave is divided into 12 *semitones.* Many modern musicians make them equal, though this be contrary to the principles of harmony, because no one fifth or third is perfectly exact, and the effect is the same as if these tones were not perfectly in tune. They likewise admit, that we must give up exactness of accord in order to obtain the advantage of equality of semitones, so that the transposition from any one tone whatever to another may in no respect injure the melody. They acknowledge, however, that the same piece played in the tone C or a half-tone higher, that is Cs, must considerably affect its nature. It is evident, therefore, that in fact all semitones are not equal, whatever efforts

may be made by musicians to render them su
because true harmony resists the execution of a
sign contradictory to its nature. Such, then, is t
real origin of the musical notes already in use; th
are derived from the numbers 2, 3, and 5. Were w
further to introduce number 7, that of the tones o
an octave would be increased, and the art of musi
carried to a higher degree of perfection. But her
the mathematician gives up the musician to the
direction of his ear.

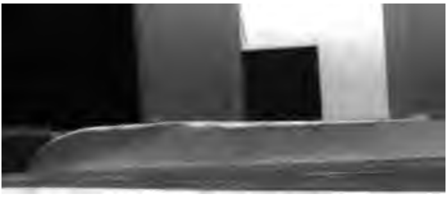
3d May, 1760.

LETTER VIII.

Of the Pleasure derived from fine Music.

It is a question as important as curious, whence is it that a fine piece of music excites a sentiment of pleasure? The learned differ on this subject. Some pretend that it is mere caprice, and that the pleasure produced by music is not founded on reason, because what is grateful to one is disgusting to another. Far from deciding the question, this renders it only more complicated. The very point to be determined is, how comes it that the same piece of music produces effects so different, since all admit that nothing happens without reason? Others maintain that the pleasure derived from fine music consists in the perception of the order which pervades it. This opinion appears at first sight sufficiently well founded, and merits a more attentive examination. Music presents objects of two kinds, in which order is essential. The one relates to the difference of the sharp or flat tones; and you will recollect, that it consists in the number of vibrations performed by each note in the same time. This difference, which is perceptible between the quickness of the vibrations of all sounds, is what is properly called harmony. The

effect of a piece of music, of which we feel the relations of the vibrations of all the notes that compose it, is the production of harmony. Thus, two notes which differ an octave excite a perception of the relation of 1 to 2; a fifth, of that of 2 to 3; and a greater third, of that of 4 to 5. We comprehend, then, the order which is found in harmony, when we know all the relations which pervade the notes of which it is composed; and it is the perception of the ear which leads to this knowledge. This perception, more or less delicate, determines why the same harmony is felt by one, and not at all by another, especially when the relations of the notes are expressed by somewhat greater numbers. Music contains, besides harmony, another object equally susceptible of order, namely, the *measure*, by which we assign to every note a certain duration; and the perception of the measure consists in the knowledge of this duration, and of the relations which result from it. The drum and tymbal furnish the example of a music in which measure alone takes place, as all the notes are equal among themselves, and then there is no harmony. There is likewise a music consisting wholly in harmony, to the exclusion of measure. This music is the *choral*, in which all the notes are of the same duration; but perfect music unites harmony and measure. Thus the connoisseur who hears a piece of music, and who comprehends, by the acute perception of his ear, all the proportions on which both the harmony and the measure are founded, has certainly the most perfect knowledge possible of that music: while another, who perceives these proportions only in part, or not at all, understands nothing of the matter, or possesses at most a very slender knowledge of it. But the sentiment of pleasure excited by fine music must not be confounded with the knowledge of which I have been speaking, though it may be confidently affirmed, that a piece of music cannot produce any, unless the relations of it are perceived. For this knowledge alone is not sufficient to excite the sentiment of pleasure; something more is wanting, which no one hitherto has unfolded. In order to be convinced that the perception alone of all the proportions of a piece of music is insufficient to produce pleasure, you have only to consider music of a very simple construction, such as goes in octaves alone, in which the perception of proportions is undoubtedly the easiest. Such music would be far from conveying pleasure, though you might have the most perfect knowledge of it. It will be said, then, that pleasure requires a knowledge not quite so easily attained—a knowledge that occasions some trouble; which must, if I may use the expression, cost us something. But, in my opinion, neither is this a satisfactory solution. A dissonance, the relations of which are expressed by the highest numbers, is caught with more difficulty; a series of dissonances, however, following without choice, and without design, cannot please. The composer must therefore have pursued in his work a certain plan, executed in real and perceptible proportions. Then a connoisseur, on hearing such a piece, and comprehending, besides the proportions, the very plan and design which the composer had in view, will feel that satisfaction which constitutes the pleasure procured by exquisite music to an ear accustomed to relish the beauties and delicacies of that enchanting art. It arises, then, from divining in some measure the views and feelings of the composer, whose execution, when fortunate, fills the soul with an agreeable sensation. It is a satisfaction somewhat similar to that which is derived from the sight of a well-acted pantomime, in which you may conjecture, by the gesture and action, the sentiments and dialogue intended to be expressed, and which presents besides a well-digested plan. The enigma of the chimney-sweeper, which was so diverting to your highness, furnishes



me with another excellent comparison. When you can guess the sense, and discover that it is perfectly expressed in the proposition of the enigma, you feel a very sensible pleasure on making the discovery; but insipid and incongruous enigmas produce none. Such are, if I may be permitted to judge, the true principles on which decisions respecting the excellence of musical compositions are founded.

6th May, 1760.

LETTER IX.

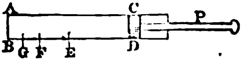
Compression of the Air.

The explanation of sound, which I have had the honour to present to your highness, leads me forward to a more particular consideration of air, which, being susceptible of a movement of vibration, such as that by which musical strings, bells, and other sonorous bodies are agitated, transmits the concussion to our ears. It will be immediately asked, what is air? For it does not appear at first sight to be a material substance. As we perceive no sensible body in it, surrounding space seems to contain no matter whatever. We feel nothing; we can walk, and move every limb in it, without experiencing the slightest obstacle. But you have only to move your hand briskly to be sensible of some resistance, and even to perceive a stream of wind excited by that rapid movement. Now the wind is nothing else but air put in motion; and seeing it is capable of producing effects so surprising, how is it possible to doubt that air is a material substance, and consequently a body? For the terms *body* and *matter* are synonymous.*

* Body rather implies a quantity of matter in some definite shape, so as to be easily considered as distinct from other matter, as the earth, a stone, a bullet, &c.—*Am. Ed.*

Body is divided into two great classes, solid and fluid.* The air, it is evident, must be referred to the class of fluids. It has several properties in common with water; but it is much more subtile and fine. Experiments have ascertained that air is about 800 times more subtile and more rarefied than water; and that if air were to be rendered 800 times denser than it is, it would have the same consistency as the other fluid.† A principal property of air, by which it is distinguished from other fluids, is its quality of being compressed, or reduced into a smaller space. This is demonstrated by the following experiment: Take a tube of metal or glass A B C D *Fig.* 2, close shut at the end A B, and open at the other, into which is introduced a piston P, filling exactly the cavity of the tube. On pushing the piston inwards, when it has arrived at the middle E, the air which occupied at first the cavity A B C D will be reduced one-half, and consequently will have become twice as dense. If the piston is pushed still farther in, as far as F, half-way between B and E, the air will be reduced to a space four times smaller than at first; and if you continue to drive forward the piston to G, so that B G shall be the half of B F, or the eighth part of the whole length B D, the same air which in the beginning was expanded over the whole cavity of the tube will be contracted to a space eight times smaller. Going on in the same manner to contract it into a space 800 times smaller, you will obtain an air 800 times denser than ordinary air. It would

Fig. 2.



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* Matter is generally considered to exist in one of three classes or forms, viz. solid, liquid, or aeriform. The same kind of matter is occasionally found in each of these forms, as in the case of ice, water, and steam.—*Am. Ed.*

† It by no means follows, that because water is 800 times more dense than air, the latter if condensed to 1-800th part of its bulk would become liquid like water.—*Am. Ed.*

then be as dense as water, which it would be easy to prove by other experiments. Hence it appears that air is a fluid substance, capable of compression, or, in other words, of being reduced to a smaller space; and in this respect it differs entirely from water. For let the tube A B C D be filled with this last fluid, and attempt to introduce the piston, you will find it impossible to drive it forward. Employ what force you may, you will gain nothing; the tube will burst sooner than you can reduce the water to a space sensibly smaller. This then is the essential difference between air and water: the latter is susceptible of no compression, but air may be compressed to any degree you please. The more the air is compressed the denser it becomes: thus the air which occupied a certain space, when compressed or reduced to half that space, becomes twice as dense; if reduced to a space 10 times smaller, it is rendered 10 times more dense; and so on. I have already remarked, that could it be rendered 800 times more dense, it would then be as dense as water, and consequently as heavy; for weight increases in the same proportion as density. *Gold*, the heaviest substance with which we are acquainted,* is likewise the most dense. It is found by experiment to be 19 times heavier than water: so that a mass of *gold* in the form† of a cube of one foot would weigh 19 times a mass of *water* of the same dimensions. Now such a mass of *water* weighs 70 pounds; the mass of *gold* therefore would weigh 19 times 70, that is, 1330 pounds. It follows, that were it possible to compress air till it were reduced to a space 19 times 800, that is, 15,200 times smaller, it would become as dense and as weighty as gold.

But it is very far from being possible to carry the compression of air to that degree. You may at first without difficulty drive forward the piston, but the farther you advance, the resistance becomes m powerful; and before you are able to reduce the to a space 10 times smaller, such a force must employed as would burst the tube, unless it w of uncommon strength. And not only would suc force be necessary to drive the piston farther, b an equal force would be requisite to keep it in th state; for on the slightest relaxation of the pow the compressed air would drive it backward. Th more compressed the air is, the more violent are its efforts to expand, and to recover its natural state. This is what we call the spring or elasticity of the air, of which I propose to treat in my next Letter.

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* Platinum, a metal discovered since this was written, is 22 times heavier than water.—*Ed.*

† The *form* is unessential.—*Am. Ed.*

10th May, 1760.

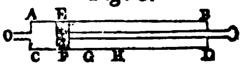
LETTER X.

Rarefaction and Elasticity of the Air.

I have remarked, that air is a fluid about 800 times more subtile than water; so that could water, without being reduced to vapour, be expanded over a space so many times greater, and could it become of consequence so many times more subtile, it would be of a similar consistence with the air which we breathe. But air has a property which water has not, that of suffering compression into a smaller space, and of being proportionably condensed, as I demonstrated in the preceding letter. And we discover in air another property no less remarkable: it is capable of being expanded over a greater space, and thus rendered still more subtile. This operation is called the rarefaction of air.

You have only to take, as before, a tube A B C D, *Fig*. 3, at the bottom of which A C let there be a small aperture O, so that, on introducing the piston as far as to E F, the air

Fig. 3.



may escape by that aperture without being condensed. The air which now occupies the cavity A C E F will then be in its natural state; let the aperture O be closely stopped. On drawing back the piston, the air will gradually expand through the greater space, so that when the piston is brought back to the point G, the space C G being double the space C F, the same air which was contained in the space A C E F will fill a space twice as great; it will be of course only half as dense, or, which is the same thing, twice as rare. If you draw back the piston to the point H, the space C H being four times as great as the space C F, the air will become four times as rare as it was at first, as it is then expanded over a space four times as great. And could the piston be drawn back till the space became 1000 times as great, the air would still equally expand through that space, and consequently become 1000 times as rare. Here then, likewise, air differs essentially from water: for if the cavity A C E F were filled with water, to no purpose would you draw back the piston; the water would continue to occupy the same space as at first, and the rest would remain empty. Hence we see that the air possesses an intrinsic power of expanding itself more and more, which it exerts not only when it is condensed, but also when rarefied. In whatever state of condensation or rarefaction the air may be, it makes unremitting efforts to extend itself over a larger space, and is continually expanding so long as it meets no obstacle. This property is called the elasticity of air; and it has been demonstrated, by experiments which I shall presently describe, that this elastic power is in proportion to the density; in other words, the more the air is condensed, the greater are its efforts to expand itself; and the more rarefied it is, the feebler are those efforts. It will be demanded, perhaps, why the air now in my chamber does not make its escape by

the door, being endowed with an expansibility continually impelling it to occupy a greater space ? Th answer is obvious. This would infallibly happe did not the external air make equal efforts to exten itself; but the efforts of the air of the chamber t get out, and that of the external air to press in being equal, they balance each other, and remain in a state of rest. Had the external air accidentally acquired a greater degree of density, that is, more elasticity, it would in part force its way into the chamber, where the air, being compressed, would likewise acquire a greater degree of elasticity; this current would accordingly last till the elasticity of the internal became equal to that of the external air. And should the air of the chamber suddenly become more dense, and its elasticity greater than that of the external air, it would force its way out; and its density gradually diminishing, its elasticity too would diminish, till it became equal to the external air; the current would then cease, and the air in the chamber would be in equilibrium with the external. Free air, then, is in a state of rest only when it has the same degree of elasticity with that which surrounds it; and as soon as that of the one tract becomes more or less elastic than the adjoining, the equilibrium can no longer subsist; but if the elasticity is greater, the air will expand itself, and slide into spaces where it is smaller: and from this motion of the air results the wind. Hence it comes to pass that the elasticity of the air is sometimes greater, sometimes less, in the same place; and this variation is indicated by the *barometer*, the description of which merits a particular consideration. I confine myself at present to these qualities of air, its *condensation* and *rarefaction*, entreating you to recollect, that the more condensed it is, the greater power of expansion or elasticity it acquires; and that, on the contrary, the more it is rarefied, the more this quality is diminished. Experimental philosophers have invented one machine for rarefying air, and another for condensing it: the former is called the *air-pump*, the latter the *condenser*. These machines serve to perform many curious experiments, with which you are already well acquainted. I reserve to myself, however, the liberty of recapitulating some of them, because they are necessary to elucidate and explain the nature and properties of air, which, as they powerfully contribute to the preservation of animals, and the production of plants, press upon us the importance of forming a just idea of them.

14*th May*, 1760.

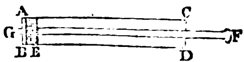
LETTER XI.

Gravity of the Air.

I HAVE endeavoured to demonstrate that the air is a fluid, endowed with the particular property of suffering compression into a smaller space, and of expanding into a greater, when no obstacle interposes. This property of air, known by the name of spring, or elasticity, from its resemblance to a spring, which it requires an effort to unbend, and which resumes its form as soon as the effort ceases, is accompanied by another, in common to it with all bodies in general, namely, gravity or weight, in virtue of which all bodies tend towards the centre of the earth, and by which they are under the necessity of falling down, unless supported. The learned are very much divided, and very uncertain, respecting the primary and mechanical cause of this power; but its existence is indubitable. Daily experience evinces it. We know even the quantity of it, and can measure it exactly. For the weight of a body is nothing else but the power which constrains it to descend; and as the weight of every body may be exactly meas-

ured, we know perfectly well the effect of gravity, though the cause, or that invisible power which acts upon all bodies, forcing them to descend, may be absolutely unknown to us. It follows, that the more matter any body contains, the heavier it is. Gold and lead are heavier than wood or feathers, as they contain more matter in the same bulk, or in the same extent. But as air is a very subtile and thin substance, and its gravity of consequence very little, this property usually escapes our senses. Experiments, however, may be made capable of producing full conviction that it possesses gravity. You have seen how the air may be rarefied in a vessel or a tube; and by means of the air-pump, this rarefaction may be carried so far as almost entirely to exhaust the air, and to leave the receiver sensibly a vacuum. Or you may make a tube A B C D, *Fig.* 4, into which you introduce the piston F E, so as perfectly to touch the bottom, and to leave no air between the two surfaces. To perform the experiment with more advantage, let there be at the bottom of the tube a little aperture G, through which the air may escape as the piston is pushed forward. Let the aperture then be closely stopped, that not a particle of air may be included between the piston and the bottom of the tube. Having made this arrangement, draw back the piston; and the external air not being able to force its way into the tube, there will remain between the bottom of the tube and the piston a perfect vacuum, which may be increased at pleasure by continuing to draw back the piston. You may thus exclude the air contained in a vessel; and such vessel, reduced to a vacuum, being tried in accurate scales, will be found to weigh less than when filled with air. Hence we deduce this very important conclusion, that the air con-

Fig. 4.



tained in an empty vessel* increases its weight, and that the air itself possesses gravity. Were the vessel large enough to contain 800 pounds weight of water, we might discover by this experiment that the body of air which fills it would weigh nearly one pound. Hence we conclude, that air is 800 times lighter than water. I must be understood as speaking of the common air which surrounds us, and which we breathe; for you know, that with the assistance of art, air may be compressed by forcing it into a smaller space, and its gravity thereby increased. Were the vessel which I have mentioned to be filled with air compressed to twice the consistence of common air, it would weigh two pounds more than when empty. Were it filled with air 800 times more compressed than common air, it would weigh 800 pounds more than when empty, that is, as much as if it were filled with water. The air, then, possessing a certain degree of gravity, though in the natural state of this fluid its gravity is extremely small, it must, however, as well as all other bodies, tend towards the centre of the earth, and consequently it presses on every thing which opposes this tendency. For this reason the superior air presses downward on the inferior, and this last undergoes a compression from the weight of the whole mass of air which is above it. Hence it comes to pass, that in these regions the air has a certain degree of compression or density, which is the effect of the gravity of the superior air; and that if the superior air had more or less gravity, the air which surrounds us would likewise become more or less dense. It is thus that the air below supports the weight of the superior air, and that the more we ascend the more it loses its density, and rarefies; so that were it possible to continue to ascend, the air would at length be totally lost, or would become

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* That is, emptied of all substances except air.—*Am. Ed.*

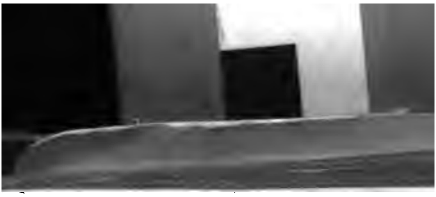
so subtile and so rarefied as to be no longer perceptible. Were you to descend, on the contrary, into a very deep pit, you would find the density of the air continually increasing, from the increase of the mass of air pressing downward upon it.

17*th May*, 1760.

LETTER XII.

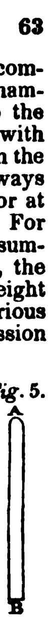
Of the Atmosphere, and the Barometer.

HAVING demonstrated that air is a fluid, elastic, and possessed of gravity, I proceed to remark, that the earth is surrounded on all sides by this fluid, and that the space which it fills is called the *atmosphere.* It would be absolutely impossible for a perfect vacuum to exist on any part of the earth's surface; for the air of the adjoining regions, compressed by the weight of the superior air, and making incessant efforts to dilate, would force itself into the empty space and fill it. The atmosphere, therefore, occupies the whole region which surrounds the earth; the inferior air is continually compressed by the weight of the superior air, and that until the degree of elasticity which results from this compression is able to form an equilibrium to the compressing power. Then, although this air is compressed only in a downward direction, it produces, in virtue of its elasticity, efforts to expand itself, not only downwards, but sideways also. For this reason, the air in a chamber is as much compressed as the external, which appeared a paradox to certain philosophers; for they reasoned thus: In a chamber, the inferior air is compressed only by the small quantity of superior air included in that chamber; whereas the external air is compressed by the weight of the whole atmosphere, the height of which is immense. But the difficulty is at once removed, by the property



which air possesses of expanding itself when compressed in all directions. Now the air in the chamber is at first reduced by the external air to the same degree of compression and elasticity with itself; hence, whether I am in my chamber or in the open air, I feel the same compression; being always understood, that I mean at the same height, or at the same distance from the centre of the earth. For I have already remarked, that on getting to the summit of a high tower, or of a lofty mountain, the compression of the air is less, because the weight of the superior air is then diminished. Various phenomena confirm this state of the compression of the air.

Fig. 5.



Take, for instance, *Fig.* 5, a tube A B, close at the end A, and having filled it with water, or any other fluid, invert it so that the open end B may be undermost, and you will find that the fluid does not run out.* The elasticity of the air acting at B, in opposition to the fluid, supports it in the tube. But if you make an aperture into the tube at A, the fluid immediately descends; the air which is admitted by the aperture acts then from above, by its pressure upon the water, and forces it downward; which demonstrates, that while the tube was close at top, it was the external air which supported the water in it. And were such a tube to be placed in a receiver, from which the air was extracted by the air-pump, the fluid would instantly descend. The ancients, to whom this property of air was unknown, alleged that nature supported the water in the tube, from the horror which it has of a vacuum. For, said they, were the fluid to descend, there must be a vacuum at the upper end of the tube, as the air could find no admission into it. According to them, therefore, it was the horror of a vacuum which kept the fluid suspended in the tube. It is now demonstrated, that it is the force of the air which supports the weight of the fluid in the tube; and as this force has a determinate quantity, the effect cannot exceed a certain limit.

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* The open end B must be kept beneath the surface of the water to answer the design of the experiment, or else be so small as to prevent the passage of air and water at the same time.—*Am. Ed.*

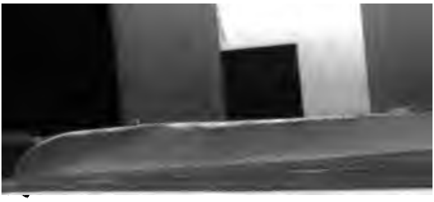
It is found by experiment, that if the tube A B is more than 33 feet in length, water will no longer remain suspended in it, but will run out till it comes to the height of 33 feet; the space left at the top will, of course, be a real vacuum. The force of the air then cannot support water in the tube at more than the height of 33 feet; and as the same force supports the whole atmosphere, it is concluded that a column of the atmosphere is of equal weight, the base being equal with a column of water 33 feet high. If, instead of water, you were to use mercury, which is 14 times heavier, the force of the air could support it in the tube at the height of only 28 inches; and if you go beyond that, the mercury descends till its height corresponds to the pressure of the atmosphere, leaving the space at the top of the tube a vacuum. Such a tube, close above and open below, being filled with mercury, forms the instrument called the *barometer*, by means of which it has been discovered that the atmosphere is not always of equal gravity. For its real gravity is ascertained by the barometer from the height of the mercury, which, as it rises or falls, indicates that the density of the air, or the pressure of the atmosphere is increasing or diminishing.

20*th May*, 1760.

LETTER XIII.

Of Air-Guns, and the Compression of Air in Gunpowder.

Having explained that remarkable property of air which is denominated compressibility, by means of



which it is reducible into a smaller space, we are enabled to give an account of several productions of both nature and art. I shall begin with an explanation of the *air-gun*, though I have no doubt but you are well acquainted with that instrument. Its construction is similar to that of the common gun; but instead of powder, we employ condensed air to discharge the bullet.

In order to comprehend the process of this operation, it must be observed that air can be compressed only by a force proportional to the degree of condensation which you wish to obtain; in this state it strives to extend itself, and the efforts which it makes are precisely equal to the force necessary to reduce it to the size which it actually occupies. The more, then, that the air is condensed, the more violent are its efforts to dilate; and if the air is raised to a density twice as great as when it is free, which is the case when we reduce it to half the space which it occupies in its natural state, the force with which it endeavours to expand is equal to the pressure of a column of water 33 feet high. Figure to yourself a great cask of this height filled with water; this fluid will undoubtedly make a stronger pressure on the bottom of the vessel. If you make a hole in it near the bottom, the water will force itself out with considerable violence; and on stopping the aperture with your finger, you will be abundantly sensible of this pressure of the water. The bottom of the cask sustains throughout a similar pressure. Now a vessel containing air twice as dense as that of the atmosphere must undergo precisely such a pressure; and if it were not sufficiently strong to sustain it, would burst. The sides, then, of this vessel must be as strong as the bottom of the cask I have mentioned. If in the same vessel the air were three times as dense as common air, the force with which it would act upon the sides must be increased in the proportion of one more, and would be the same which is sustained by the bottom of a cask full of water of 66 feet in height. You will easily conceive that this force must be very great, and that it must go on increasing in the same ratio, according to the different degrees of condensation of the air. This being laid down, there is at the bottom of the air-gun a cavity strongly fortified on all sides, into which the air is more and more compressed, in order to reduce it to as high a degree of density as the force employed for that purpose can admit. The air confined in this cavity will thereby acquire a prodigious power to force itself out; and if an aperture is made, it will fly off with a velocity proportional to that power. Now there is such an aperture, which terminates in the cavity of the tube into which the ball is put. It is closely stopped; but when you wish to discharge the piece, you open, for an instant, the valve which shuts it; and the air, rushing forth, forces out the ball with all the velocity which we remark in shooting. Every time you discharge the valve is kept open only a single moment; a certain quantity of air, therefore, and no more, can escape, and enough still will remain for several shots. But on discharge, its density and corresponding elasticity diminish; and for this reason, the latter discharges are less forcible than the former, till the force is at length entirely exhausted. Were the valve to remain open any considerable time, more air would make its escape, which would all go to waste; for this force acts upon the ball only while it is in the barrel of the gun; as soon as it is shot off, it is useless to leave a passage for the air. Hence it appears, that were it possible to carry the condensation of this fluid a great deal farther, you would produce from the wind-gun the same effects as from the guns and cannons in common use.*

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* Air-guns are now constructed so as to be used with an effect nearly equal to a common fowling-piece, but the accuracy necessary to their construction, renders them too expensive and troublesome to be substituted for common muskets.—*Am. Ed.*

The effect of artillery is accordingly founded on the same principle. Gunpowder is only a substance which contains in its pores an air extremely condensed. Nature produces here the same operations which we employ for compressing the air, but carries the condensation to a much higher degree. All that is necessary is to open the little cavities in which this dense air is confined, that it may have liberty to escape. This is performed by means of fire, which bursts open these little envelopes: the air then suddenly flies off with incredible velocity, and forces before it bullets and balls in a manner entirely similar to that which we have remarked in the case of the wind-gun, but with much greater impetuosity. Here, then, are two very surprising effects produced from the condensation of air, with this single difference, that in the one it is the work of art, and in the other that of nature. We see therefore in this, as in every thing else, how infinitely the operations of human skill are surpassed by those of nature.*

24th May, 1760.

LETTER XIV.

The Effect produced by Heat and Cold on all Bodies, and of the Pyrometer and Thermometer.

Besides the properties already mentioned, air has another very remarkable quality in common to it with all bodies, not excepting such as are solid; I mean the change produced on it by heat and cold. It is observable, in general, that all bodies, being heated, dilate or increase in size. A bar of iron made very hot, is somewhat longer and thicker than when it is cold. There is an instrument called the *pyrometer*, which accurately indicates the slightest differences of length or shortness that a bar of iron undergoes to which it is applied. You know that in a watch some of the wheels move very slowly, though they communicate motion to others which revolve with considerable rapidity. By a similar mechanism it is possible, from a change almost imperceptible, to produce one very considerable, as is the case of the pyrometer, which I have just mentioned. It has an index, which runs over a very considerable space, on the slightest change produced in the length of the body on which the experiment is made. On applying this instrument to a bar of iron, or any other metal, placed over a burning lamp, the index is immediately put in motion, and shows that the bar is becoming longer; and as the heat increases, the bar likewise increases in length. But on extinguishing the lamp, and the bar growing cold again, the index moves in a contrary direction, and thereby shows that the bar is growing shorter. The difference, however, is so slight, that without the help of this instrument it would be difficult to perceive it. Yet this variation is abundantly perceptible in the motion of pendulum time-pieces. The use of the pendulum is to regulate the motion. If you lengthen it, the clock goes slower; and if you shorten it, the clock goes faster. Now it is remarked, that in very hot weather all clocks lose time, and proportionably gain it in very cold weather; which clearly demonstrates that the pendulum is lengthened or shortened, according to the temperature of the air.

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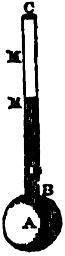
* The account here given of the nature of gunpowder, and of the effect of fire upon it is very erroneous. Air is not imprisoned, as the author supposed, in the pores of the powder. The explosive effect of gun-powder is owing to the sudden conversion of its solid particles or grains into elastic airs or gases by the touch of fire, in consequence of which it expands into many thousand times its former bulk. The nature of the gases thus rapidly formed can be understood only by an attention to the composition of the powder and the chymical changes which it undergoes by heat.—*Am. Ed.*

All bodies undergo this alteration; but the quantity differs greatly, according to the nature of the

substance of which they are composed. In fluids, especially, this variability is very perceptible. To ascertain it, take a glass tube, B C, *Fig.* 6, joined at the end B to a hollow ball A, and let it be filled with any liquor you please up to M. On heating the ball A, the liquor will rise from M towards C; when it becomes cold again, the liquor will fall towards B. This clearly proves that the same liquid occupies a greater space when it is heated, and a smaller when cold. It is likewise clear, that this variation must be more perceptible when the ball is large and the tube narrow. For if the whole mass of liquor increases or diminishes by a thousandth part, that thousandth part will occupy, in the tube, a space great in proportion to its narrowness. Such an instrument then is exceedingly proper to indicate to us the different degrees of heat and cold; for if the liquor rises or falls, it is a certain indication that the heat is increasing or diminishing. This instrument is called the *thermometer*,* which points out

Fig. 6.



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* Of this instrument there are three kinds now in use, viz. *Fahrenheit's*, *Reaumur's*, and *Celsius's* or the *centigrade* thermometer. In the *first* of these, which is used in Britain and North America, the freezing point is at 32°, and the boiling point at 212°, the interval being 180°. In *Reaumur's*, which is used in Switzerland, Italy, and part of Germany, the scale begins at the freezing point, and the boiling point is placed at 80°, the interval being 80°. In the *centigrade* thermometer, which is used in France, Sweden, and Denmark, the freezing point is at 0°, and the boiling point at 100°.

The freezing point of the thermometer is immoveable, unless when the bulb containing the mercury has changed its form, which has been recently supposed to take place in consequence of the vacuum above the mercury, which exposes the bulb to the pressure of the atmosphere. The boiling point is, however, variable, depending on the pressure of the atmosphere. Near the surface of the earth it varies 1° of Fahrenheit for every 530 feet of altitude, or for 0·589 inches of the barometer. By measuring therefore the temperature at which water boils, we may determine the height of the place This method was first suggested by Fahrenheit and Cavallo, but has been perfected by the Rev. F. J. H. Wollaston, who has given an account of this thermometrical barometer in the *Philosophical Transactions* for 1817, p. 183.—*Ed.*

A fourth kind of graduation, called De Lisle's thermometer, has been the changes that take place in the temperature of the air, and of the bodies that surround us. It must not be confounded with the *barometer*, whose use is to indicate the gravity of the air, or rather the force with which it is compressed. This caution is the more necessary, that the barometer and thermometer have a considerable resemblance: being both glass tubes filled with mercury; but their construction and the principles on which they are founded are entirely different. This quality of bodies, extension by heat and contraction by cold, belongs likewise in a very superior degree to air. I shall explain it at greater length in my next Letter.

27th May, 1760.

LETTER XV.

Changes produced in the Atmosphere by Heat and Cold.

Heat and cold produce the same effect on air as on every other body. Air is rarefied by heat, and condensed by cold. From what I have said of the elasticity of air, you easily perceive that a certain quantity of this fluid is not determined to occupy only a certain space, as all other bodies are; but by its nature it has a perpetual tendency to dilate, and actually does expand itself, as long as it meets no obstacle.

This property of air is denominated *elasticity*. When this fluid is confined in a vessel, it makes efforts in every direction to burst it; and these efforts are greater or less in proportion to its condensation. Hence we come to this conclusion, that the elasticity of air is in exact proportion to its density; so

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used to some extent, chiefly in Russia. The scale commences at the boiling point, and descends to the freezing, which is marked 150°. Fahrenheit's scale is the one in common use in the United States, although the centigrade is sometimes employed for philosophical purposes.—*Am. Ed.*

that when its density is doubled, its elasticity is likewise doubled; and that, in general, a certain degree of elasticity corresponds to a proportional degree of density. It must be remarked, however, that this takes place no longer than while the air preserves the same degree of heat. Whenever it becomes hotter, it acquires greater power of expansion than what corresponded to its density; and cold produces the opposite effect, by diminishing its expansive power. In order then to determine the elasticity of a mass of air, it is not sufficient to know its density; you must likewise know its degree of heat. In order to set this in a clear light, let us suppose two chambers closely shut on all sides, but united by a door of communication: and that the heat in both is equal. In order to this the air in both chambers must have the same degree of density. For were the air more dense, and consequently more elastic, in the one than in the other, part of it would escape from the one, and force its way into the other, till the density in both were the same. But let us suppose that one of the chambers has become hotter than the other, the air thereby acquiring a greater elasticity, would of course force itself into the other, and reduce that which it found there into a smaller space, till the elasticity in both chambers was brought to the same degree. During this change there will be a current of air through the door, from the chamber which is more into that which is less heated; and when the equilibrium is restored, the air will be more rarefied in the warm apartment, and more condensed in the cold; and yet the elasticity of both will be the same. From this it clearly follows, that two masses of air of different densities may have the same elasticity, when the one is hotter than the other; and this circumstance taken into consideration, it may happen, that with the same degree of density, they may be endowed with different degrees of elasticity.

What I have said of two chambers may be applied to two countries; and hence it may be concluded, that when one country becomes warmer than the other, there must of necessity be a current of air from the one to the other; and from this results the wind.

Here, then, is one fruitful source of winds, though there are perhaps others, which consist in different degrees of heat which prevail in different regions of the earth; and it is demonstrable, that the whole air which surrounds the earth could not be in a state of rest unless that, universally, at equal heights, there were found the same degree, not only of density, but likewise of heat. And should it happen that there were no wind over the whole surface of the earth, it might with certainty be concluded that the air would likewise be everywhere equally dense and warm at equal heights. Now, as this never happens, there must of necessity always be winds, at least in some regions. But these winds are, for the most part, to be met with only on the surface of the earth; and the higher you rise, the less violent winds are. Winds are hardly perceptible at the summit of very high mountains; there perpetual tranquillity reigns; from which it is impossible to doubt that at considerable elevations the air is always in a state of rest. Hence it follows, that in regions remarkably elevated, there universally prevails all over the earth the same degree of density and heat; for were it hotter in one place than in another, the air could not be in a state of rest. And as there is no wind in these elevated regions, it must necessarily follow, that the degree of heat there must be always the same; which is a very surprising paradox, considering the great variations of heat and cold which we feel on the surface of the earth, during the course of a year, and even of one day; without taking into the account the difference of climate, that is, the intolerable heats felt under the equator, and the dreadful cold which constantly prevails towards the poles of the earth. Experience itself, however, confirms the truth of this astonishing fact. The snow and ice remain equally, summer and winter, on the mountains of Switzerland, and are equally unchangeable on the Cordilleras, lofty mountains of Peru, situated under the very equator, and where there perpetually reigns, nevertheless, a cold as excessive as that of the polar regions. The height of these mountains is $4\frac{3}{5}$ English miles, or 24,000 feet. From this it may be with confidence concluded, that were it possible for us to ascend to the height of 24,000 feet above the earth, we should always meet with the same degree of cold, and that cold excessively severe. We should remark there no sensible difference during either summer or winter, under the equator, or near the poles. At this height, and still higher, the state of the atmosphere is universally, and at all seasons, the same; and the variations of heat and cold take place near the surface of the earth alone. It is only in these inferior regions that the effect of the rays of the sun becomes perceptible. You have, undoubtedly, some curiosity to know the reason of this. It shall be the subject of the following Letter.

31st May, 1760.

LETTER XVI.

The Cold felt on high Mountains and at great Depths accounted for.

It appears very surprising, that we should feel the same degree of cold in all regions, after we have risen to a certain height, say 24,000 feet; considering that the variations with respect to heat on the earth, not only in different climates, but in the same country, at different seasons of the year, are so perceptible.* This variety, which takes place at the surface of the globe, is undoubtedly occasioned by the sun. It appears, at first sight, that his influence must be the same above and below, especially when we reflect, that a height of 24,000 feet, though very great with respect to us, and even far beyond the height of very lofty mountains, is a mere nothing, compared to the distance of the sun, which is about ninety-six millions of miles. This is, therefore, a very important difficulty, which we must endeavour to solve. For this purpose I begin with remarking, that the rays of the sun do not communicate heat to any bodies but such as do not grant them a free passage. You know that bodies through which we can discern objects are denominated *transparent*, *pellucid*, and *diaphanous*. These bodies are glass, crystal, diamond, water, and several other liquids, though some are more or less transparent than others. One of these transparent bodies being exposed to the sun, is not heated to such a degree as a body not transparent, as wood, iron, &c. Bodies not transparent are denominated *opaque*. A burning-glass, for example, by transmitting the rays of the sun, sets on fire opaque bodies, while the glass itself is not sensibly heated. Water exposed to the sun becomes somewhat warm, only because it is not perfectly transparent; when we see it considerably heated by the sun at the brink of rivers, it is because the bottom, being an opaque body, is heated by the rays which the water transmits. Now, every heated body communicates that heat to all adjoining bodies; the water accordingly derives heat from the bottom. If the water be very deep, so that the rays cannot

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* The same degree of cold is not felt at the same height in all regions. On ascending to a certain height we arrive at the line or term of perpetual congelation, where snow or ice would never melt. This line is at the equator at the height of 15,577 feet; in the latitude of 45° its height is 7658 feet; in the latitude of 80° it is 120 feet, and it just grazes the surface of the earth at the poles. The influence of this line upon the phenomena of the weather is very important.—*Am. Ed.*

penetrate to the bottom, it has no perceptible heat, though the sun bears upon it.

As air is a very transparent body to a much higher degree than glass or water, it follows that it cannot be heated by the sun, because the rays are freely transmitted through it. The heat which we frequently feel in the air is communicated to it by opaque bodies, which the rays of the sun have heated; and were it possible to annihilate all these bodies, the air would scarcely undergo any change in its temperature by the rays of the sun: exposed to it or not, it would be equally cold. But the atmosphere is not perfectly transparent: it is even sometimes so loaded with vapours that it loses almost entirely its transparency, and presents only a thick fog. When the air is in this state, the rays of the sun have a more powerful influence upon it, and heat it immediately.

But these vapours rise to no great height; at the height of 24,000 feet, and beyond, the air is so subtile and so pure, that it is perfectly transparent; and for this reason the rays of the sun cannot immediately produce any effect upon it. This air is likewise too remote from terrestrial bodies to receive a communication of heat from them; they act only upon such as are adjacent. Hence you will easily perceive that the rays of the sun cannot produce any effect in regions of the air very much elevated above the surface of the earth; and that the same degree of cold must always and universally prevail in such regions, as the sun has no influence there, and as the heat of terrestrial bodies cannot be communicated so far. This is nearly the case on the summit of very high mountains, where it is always much colder than on plains and in valleys.

The city of Quito, in Peru, is almost under the equator, and were we to form our judgment from its situation on the globe, we would suppose it oppressed with intolerable heat; the air, however, is abundantly temperate, and differs very little from that of Paris. Quito is situated at a great height above the real surface of the earth. In going to it from the seashore you have to ascend for several days; it is accordingly built at an elevation equal to that of our highest mountains, though surrounded by others still much higher, called the Cordilleras. This last circumstance would afford a reason for thinking that the air there must be as hot as at the surface of the earth, as it is contiguous on all sides to opaque bodies, on which the rays of the sun fall. The objection is solid; and no solution can be given but this:—That the air of Quito, being very elevated, must be much more subtile, and of less gravity than with us; and the barometer, which always stands considerably lower, incontestably proves it.

Air of such a quality is not so susceptible of heat as common air, as it must contain less vapour and other particles which usually float in the atmosphere; and we know by experience that air very much loaded is proportionably susceptible of heat. I must here subjoin another phenomenon no less surprising:—In very deep pits, and lower still, if it were still possible to descend, the same degree of heat always and universally prevails, and nearly for the same reason.* As the rays of the sun exert their influence only on the surface of the earth, and as the heat which they there excite communicates itself up and down, this effect at very great depths is almost imperceptible. The same thing holds respecting considerable heights.

3d June, 1760.

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* It has been recently found, that in descending deep mines, the temperature, instead of being uniform, increases considerably, amounting in some cases to about 12° of Fahrenheit at a depth of 500 feet.—*Ed.*

LETTER XVII.

Of Light, and the Systems of Descartes and Newton.

Having spoken of the rays of the sun, which are the focus of all the heat and light that we enjoy, you will undoubtedly ask, What are these rays? This is, beyond question, one of the most important inquiries in physics, as from it an infinite number of phenomena is derived. Every thing that respects light, and that renders objects visible, is closely connected with this inquiry. The ancient philosophers seem to have taken little interest in the solution of it. They contented themselves with saying that the sun is endowed with the quality of shining, of giving heat and light. But is it not worth while to inquire, Wherein does this quality consist? Do certain portions, inconceivably small, of the sun himself, or of his substance, come down to us? Or, is the transmission similar to the sound of a bell, which the ear receives? though no part of the substance of the bell be separated from it—as I observed in explaining the propagation and perception of sound.

Descartes, the first of modern philosophers, maintained this last opinion; and having filled the whole universe with a subtile matter composed of small globules, which he calls the second element, he supposes that the sun is in a state of continual agitation, which he transmits to these globules, and pretends that they again communicate their motion in an instant to every part of the universe. But since it has been discovered that the rays of the sun do not reach us instantaneously, and that they take eight minutes to fly through that immense distance, the opinion of *Descartes*, which laboured besides under other difficulties, has been given up.

The great *Newton* afterward embraced the former system, and maintained that the luminous rays are really separated from the body of the sun, and the particles of light thence emitted with that inconceivable velocity which brings them down to us in about eight minutes. This opinion, which is that of most modern philosophers, particularly the English, is called *the system of emanation*—it being imagined that rays emanate from the sun and other luminous bodies, as water emanates or springs from a fountain.

This opinion appears at first sight very bold, and irreconcilable to reason. For were the sun emitting continually, and in all directions, such floods of luminous matter, with a velocity so prodigious, he must speedily be exhausted; or at least some alteration must, after the lapse of so many ages, be perceptible. This, however, is contradicted by observation. It cannot be a matter of doubt, that a fountain which should emit streams of water in all directions would be exhausted in proportion to the velocity of the emission; much more the sun, whose rays are emitted with a velocity so inconceivable. Let the particles of which rays of light are formed be supposed as subtile as you please, nothing will be gained; the system will ever remain equally untenable. It cannot be affirmed that this emanation is not made in all directions; for wherever you are placed, the whole sun is visible, which proves incontestably that rays from every point of the sun are emitted towards the spot which you occupy. The case is very different from that of a fountain, which should emit streams of water in all directions. For one point in the fountain could furnish only one stream directed to a particular spot; but every point of the sun's surface must emit an infinite number, diffusing themselves in all directions. This circumstance alone infinitely increases the expenditure of luminous matter, which the sun would have to make.

Another difficulty, and which appears equally insuperable, is, that the sun is not the only body which

emits rays, but that all the stars have the same quality; and as everywhere the rays of the sun must be crossing the rays of the stars, their collision must be violent in the extreme. How must their direction be changed by such collision! This collision must take place with respect to all luminous bodies visible at the same time. Each, however, appears distinctly, without suffering the slightest derangement from any other—a certain proof that many rays may pass through the same point without disturbing each other, which seems irreconcilable to the system of emanation. Let two fountains be set a playing upon each other, and you will immediately perceive their different streams disturbed and confounded: it must of consequence be concluded, that the motion of the rays of light is very essentially different from that of a *jet d'eau*, and in general from all substances forcibly emitted.

Considering afterward transparent bodies through which rays are freely transmitted in all directions, the supporters of this system are under the necessity of affirming, that these bodies contain pores, disposed in straight lines, which issue from every point of the surface, and proceed in all directions; it being inconceivable how there could be any line through which a ray of the sun might be transmitted with such amazing velocity, and even without the slightest collision. Here then are bodies wonderfully porous, which have the appearance nevertheless of being extremely solid.

Finally, in order to enjoy vision, the rays must enter into the eye, and penetrate its substance with the same velocity. All these difficulties taken together will, I doubt not, sufficiently convince you that the system of emanation has in no respect a foundation in nature; and you will certainly be astonished that it could have been conceived by so great a man, and embraced by so many enlightened philosophers. But it is long since Cicero remarked, that nothing so absurd can be imagined as to find no supporter among philosophers. For my own part, I am too little a philosopher to adopt the opinion in question.

7th June, 1760.

LETTER XVIII.

Difficulties attending the System of Emanation.

HOWEVER strange the doctrine of the celebrated *Newton* may appear, that rays proceed from the sun by a continual emanation, it has, however, been so generally received, that it requires an effort of courage to call it in question. What has chiefly contributed to this is, no doubt, the high reputation of the great English philosopher, who first discovered the true laws of the motions of the heavenly bodies; and it was this very discovery which led him to the system of emanation.

Descartes, in order to support his theory, was under the necessity of filling the whole space of the heavens with a subtile matter, through which all the celestial bodies move at perfect liberty. But it is well known, that if a body moves in air it must meet with a certain degree of resistance; from which *Newton* concluded, that however subtile the matter of the heavens may be supposed, the planets must encounter some resistance in their motions. But, said he, this motion is not subject to any resistance: the immense space of the heavens, therefore, contains no matter. A perfect vacuum, then, universally prevails. This is one of the leading doctrines of the Newtonian philosophy, that the immensity of the universe contains no matter in the spaces not occupied by the heavenly bodies. This being laid down, there is between the sun and us, or at least from the sun down to the atmosphere of the earth, an abso-

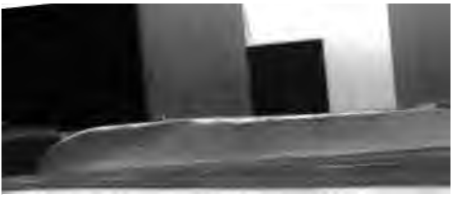
lute vacuum. In truth, the farther we ascend, the more subtile we find the air to be; from whence it would apparently follow, that at length the air would be entirely lost. If the space between the sun and the earth be an absolute vacuum, it is impossible that the rays should reach us in the way of communication, as the sound of a bell is transmitted by means of the air. For if the air intervening between the bell and our ear were to be annihilated, we should absolutely hear nothing, let the bell be struck ever so violently.

Having established, then, a perfect vacuum between the heavenly bodies there remains no other opinion to be adopted but that of emanation; which obliged *Newton* to maintain, that the sun and all other luminous bodies emit rays which are always particles, infinitely small, of their mass, darted from them with incredible force. It must be such to a very high degree, in order to impress on rays of light that inconceivable velocity with which they come from the sun to us in the space of eight minutes. But let us see whether this theory be consistent with *Newton's* leading doctrine, which requires an absolute vacuum in the heavens, that the planets may encounter no manner of resistance to their motions. You must conclude, on a moment's reflection, that the space in which the heavenly bodies revolve, instead of remaining a vacuum, must be filled with the rays, not only of the sun, but likewise of all the other stars which are continually passing through it from every quarter, and in all directions, with incredible rapidity. The heavenly bodies which traverse these spaces, instead of encountering a vacuum, will meet with the matter of luminous rays in a terrible agitation, which must disturb these bodies in their motions much more than if it were in a state of rest.

Thus *Newton*, apprehensive lest a subtile matter, such as *Descartes* imagined, should disturb the motions of the planets, had recourse to a very strange expedient, and quite contradictory to his own intention, as, on his hypothesis, the planets must be exposed to a derangement infinitely more considerable. I have already submitted to you several other insuperable objections to the system of emanation; and we have now seen that the principal, and indeed the only reason which could induce *Newton* to adopt it, is so self-contradictory as wholly to overturn it. All these considerations united, leave us no room to hesitate about the rejection of this strange system of the emanation of light, however respectable the authority of the philosopher who invented it.

Newton was without doubt one of the greatest geniuses that ever existed. His profound knowledge, and his acute penetration into the most hidden mysteries of nature, will be a just object of admiration to the present and to every future age. But the errors of this great man should serve to admonish us of the weakness of the human understanding, which, after having soared to the greatest possible heights, is in danger of plunging into manifest contradiction.

If we are liable to weaknesses and inconsistencies so humiliating, in our researches into the phenomena of this visible world, which lies open to the examination of our senses, how wretched must we have been had God left us to ourselves with respect to things invisible, and which concern our eternal salvation! On this important article a revelation was absolutely necessary to us; and we ought to avail ourselves of it with the most profound veneration. When it presents to us things which may appear inconceivable, we have but to reflect on the imperfection of human understanding, which is so apt to be misled, even as to sensible objects. Whenever I hear a pretended freethinker inveighing against the truths of religion, and even sneering at it with the most arrogant self-sufficiency, I say to myself, Poor weak



mortal, how inexpressibly more noble and sublime are the subjects which you treat so lightly than those respecting which the great *Newton* was so grossly mistaken! I could wish your highness to keep this reflection ever in remembrance; occasions for making it occur but too frequently.

10*th June*, 1760.

LETTER XIX.

A different System respecting the Nature of Rays and of Light, proposed.

You have seen that the system of the emanation of the rays of light labours under insuperable difficulties, and that the doctrine of a vacuum for the heavenly bodies to range in is equally untenable, as the rays of light would completely fill it. Two things, then, must be admitted: first, the space through which the heavenly bodies move is filled with a subtile matter; secondly, rays are not an actual emanation from the sun and other luminous bodies, in virtue of which part of their substance is violently emitted from them, according to the doctrine of *Newton*.

That subtile matter which fills the whole space in which the heavenly bodies revolve is called *ether*. Of its extreme subtilty no doubt can be entertained. In order to form an idea of it, we have only to attend to the nature of air, which, though extremely subtile, even on the surface of the earth, becomes more and more so as we ascend; and entirely ceases, if I may use the expression, when it comes to be lost in the ether. The ether, then, is likewise a fluid as the air is, but incomparably finer and more subtile, as we are assured that the heavenly bodies revolve freely through it, without meeting any perceptible

resistance. It is also, without doubt, possessed of elasticity, by means of which it has a tendency to expand itself in all directions, and to penetrate into spaces where there would otherwise be a vacuum; so that if by some accident the ether were forced out of any space, the surrounding fluid would instantly rush in and fill it again.

In virtue of this elasticity, the ether is to be found not only in the regions which are above our atmosphere, but it penetrates the atmosphere universally, insinuates itself by the pores of all bodies, and passes irresistibly through them. Were you, by the help of the air-pump, to exhaust the air from a receiver, you must not imagine that you have produced an absolute vacuum; for the ether, forcing itself through the pores of the receiver, completely fills it in an instant. Having filled a glass tube of the proper length with mercury, and immerged it, when inverted, in the cistern, in order to make a barometer, it might be supposed that the part of the tube which is higher than the mercury is a vacuum, because the air is completely excluded, as it cannot penetrate the pores of glass; but this vacuum, which is apparent only, is undoubtedly supplied by the ether, insinuating itself without the smallest difficulty.

It is by this subtilty and elasticity of ether that I shall by-and-by explain to you the remarkable phenomena of electricity. It is even highly probable that ether has an elasticity much superior to that of air, and that many of the phenomena of nature are produced by means of it. For my own part, I have no doubt that the compression of the air in gunpowder is the effect of the elastic power of ether. And as we know by experiment that the air in it is condensed almost 1000 times more than common air, and that in this state its elasticity is likewise 1000 times greater, the elasticity of the ether must in this case be so too, and consequently 1000 times greater than that of common air.* We shall then have a just idea of ether, in considering it as a fluid in many respects similar to air, with this difference, that ether is incomparably more subtile, and more elastic.

Having seen then that the air, by these very qualities, is in a proper state for receiving the agitations or shakings of sonorous bodies, and to diffuse them in all directions, as we find in the propagation of sound, it is very natural to suppose that ether may in the same circumstances likewise receive agitations in the same manner, and transmit them to the greatest distances. As the vibrations of the air produce *sound*, what will be the effect of those of ether? You will undoubtedly guess at once *light*. It appears in truth abundantly certain, that light is with respect to ether, what sound is with respect to air; and that the rays of light are nothing else but the shakings or vibrations transmitted by the ether, as sound consists in the shakings or vibrations transmitted by the air.

The sun, then, loses nothing of his substance in this case, any more than a bell in vibrating; and, in adopting this system, there is no reason to apprehend that the mass of this orb should ever suffer any diminution. What I have said of the sun must also be extended to all luminous bodies, such as fire, a wax taper, a candle, &c.

It will undoubtedly be objected, that these terrestrial luminaries evidently waste, and that unless they are continually fed and kept up, they will be speedily extinguished; that consequently the sun must in time be wasted away, and that the parallel of a bell is not accurate. But it is to be considered, that these fires, besides their light, throw out smoke, and a great deal of exhalation, which must be carefully distinguished from the rays of light. Now the smoke and exhalation evidently occasion a considerable diminution, which must not be imputed to the rays of light; for were it possible to separate them from the smoke and other exhalations, the luminous quality alone would occasion no expenditure. Mercury may, by means of art, be rendered luminous, as you have probably seen, and that without any diminution of its substance, which proves that light alone produces no waste of luminous bodies.[*] Thus, though the sun illuminates the whole world by his rays, he loses nothing of his own substance, his light being only the effect of a certain agitation, or violent concussion of his minute particles, communicated to the adjoining ether, and thence transmitted in all directions by means of this fluid to the remotest distances, as a bell when struck communicates its own agitation to the circumambient air. The more we consider this parallel between sonorous and luminous bodies, the more we shall find it conformable to nature, and justifiable by experience; whereas the more we attempt to reconcile the phenomena of nature to the system of emanation, the more difficulties we encounter.[†]

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* The author here again falls into the error of supposing that gunpowder contains air in a state of violent compression. He might by the same kind of analogy suppose elastic fluids to be compressed in other solids; for example, that ice contains steam in a state of great compression. This reasoning was pursued before the chymical nature of gases and the relations of heat to matter were so well understood as at present.—*Am. Ed.*

14th June, 1760.

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[*] Mercury cannot be heated so as to become incandescent, or emit light (which is probably the method of rendering it luminous alluded to by the author), without losing a portion of its substance by vaporization. If a piece of fine gold be suspended over heated mercury, it becomes speedily tarnished by the mercurial vapour.—*Am. Ed.*

[†] Dr. Priestley undertakes to obviate the objection to the waste of the sun so much insisted on by Euler. He collected the sun's rays from a concave reflecting surface of four square feet, and threw the focus on the arm of a delicate balance, and found that it indicated a weight not exceeding, in one second of time, the 1200-millionth part of a grain; and he therein infers by calculation, that there does not issue from one square foot of the sun's surface, in one second of time, more than one forty-thousandth part of a grain of matter, or about 4,752,000 grains—679 pounds avoirdupois in 6000 years; a quantity which would not lessen his diameter more than ten feet.—*Am. Ed.*

LETTER XX.

Of the Propagation of Light.

The propagation of light in the ether is produced in a manner similar to that of sound in the air; and just as the vibrations occasioned in the particles of air constitute sound, in like manner the vibration of the particles of ether constitutes light or luminous rays; so that *light is nothing else but an agitation or concussion of the particles of ether*, which is everywhere to be found, on account of its extreme subtilty, in virtue of which it penetrates all bodies.

These bodies, however, modify the rays of light in many different ways, by transmitting or stopping the propagation of the concussions. Of this I shall treat at large in the sequel. I confine myself at present to the propagation of rays in the ether itself, which fills the immense space in which the heavenly bodies revolve. There the propagation takes place in perfect liberty. The first thing which here presents itself to the mind is the prodigious velocity of the rays of light, which is about 900,000 times more rapid than that of sound, though this last travels no less than 1100 feet in a second.

This amazing velocity would be sufficient of itself to overturn the system of emanation; but in that which I am attempting to establish, it is a natural consequence, from the principles laid down, as I hope to demonstrate. They are the same with those on which is founded the propagation of sound in the air; and this depends at once on its density and elasticity. It is evident, that if the density of air were diminished, sound would be accelerated; and if the elasticity of the air were increased, the same thing would happen. If the density of the air diminished, and its elasticity increased at once, we should have a twofold reason for the increase of the velocity of sound. Let us conceive, then, the density of the air diminished, and its elasticity increased, till its density and elasticity became equal to those of ether, and we should then no longer be surprised that the velocity of sound had become many thousands of times greater than it actually is. For you will be pleased to remember, that according to the first ideas we formed of ether, this fluid must be inconceivably rarer and more elastic than air. Now both of these qualities equally contribute to accelerate the velocity of vibrations. From this explanation, the prodigious velocity of light is so far from presenting any thing irreconcilable to reason, that it rather perfectly harmonizes with the principles laid down; and the parallel between light and sound is in this respect so firmly established, that we may confidently maintain, that if air should become as subtile and as elastic as ether, the velocity of sound would become as rapid as that of light.

The subtilty of ether, then, and its great elasticity, are the reason which we assign for the prodigious velocity of the motion of light; and so long as the ether preserves this same degree of subtilty and elasticity, this velocity must continue the same. Now it cannot be doubted that the ether has, through the whole universe, the same subtilty and the same elasticity. For were the ether less elastic in one place than in another, it would force itself into it till the equilibrium was perfectly restored. The light of the stars, therefore, moves with as great velocity as that of the sun; and as the stars are at a much greater distance from us than the sun, a much greater quantity of time is requisite to transmit their rays to us. However great the distance of the sun may appear, whose rays, nevertheless, reach the surface of our globe in eight minutes, the fixed star nearest to us is at least 400,000 times more distant than the sun; a ray of light issuing from that star

will employ then 400,000 times eight minutes in travelling to us, that is 53,333 hours, or 2,222 days, or six years nearly.

It is then upwards of six years since the rays of light issued from that fixed star, the least remote, and probably the most brilliant, in order to render it visible to us; and these rays have employed a period so considerable to fly through the space which separates us from that star. Were God just now to create a new fixed star at the same distance, it could not become visible to us till more than six years had elapsed, as its rays require that length of time to travel this distance. Had one been created at the beginning of the world a thousand times more distant than that which I have mentioned, it could not yet be visible to us, however brilliant, as 6000 years are not yet elapsed since the creation. The first preacher of the court of Brunswick, Mr. Jerusalem, has happily introduced this thought in one of his sermons. The passage runs thus:—

"Raise your thoughts from the earth which you inhabit, to all the bodies of the vast universe, which are so far above you; launch into the immensity of space which intervenes between the most remote which your eyes are able to discover, and those whose light, from the moment of creation till now, has not as yet, perhaps, come down to us. The immensity of the kingdom of God justifies this representation." (*Sermon on the Heavens, and Eternal Beatitude.*)

I flatter myself that these reflections will excite a desire of further instruction respecting the system of light, from which is derived the theory of colours and of vision.

17th June, 1760.

LETTER XXI.

Digression on the Distances of the Heavenly Bodies, and on the Nature of the Sun, and his Rays.

THE observations which I have been making respecting the time which the light of the stars employs in making its progress down to us convey a striking idea of the extent and greatness of the universe. The velocity of sound, which flies through the space of 1000 feet* in a second, furnishes us with nearly the first standard of measurement. It is about 2000 times more rapid than the pace of a man who is a good walker. Now the velocity of the rays of light is 900,000 times still more rapid than that of sound: these rays accordingly perform every second a course of 900,000,000 of feet, or 170,000 English miles.†

What astonishing velocity! Yet the nearest fixed star is so remote, that its rays, notwithstanding this prodigious velocity, would take more than six years in descending to us. And were it possible for a great noise, such as that of the firing of a cannon, issuing from that star, to be conveyed to our ears, it would require a period of 5,400,000 years to reach us. And this is applicable only to those stars which are the most brilliant, and are probably nearest to us. Those which appear the smallest are very probably ten times still farther remote, and more. A whole century, then, at least, must elapse before the rays of these stars could possibly reach us. How prodigious must that distance be which cannot be passed through in less than 100 years, by a velocity

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* It has before been stated to be 1142 feet, which is the general estimate.—*Am. Ed.*

† 192,000 miles is the more recent estimate.—*Am. Ed.*

which flies at the rate of 170,000 English miles every second!

Were, then, one of these stars to be just now annihilated, or eclipsed only, we should still continue to see it for 100 years to come, as the last rays which it emitted could not reach us in less time.

The generality of mankind is very far from having any thing like just ideas respecting the vast extent of the universe. Many consider it as a work of little importance, which chance alone might have produced. But what must be the astonishment of one who reflects, on observing that all these immense bodies are arranged with the most consummate wisdom; and that the more knowledge we acquire on the subject, though it must ever be very imperfect, the more we must be disposed to admire their order and magnificence!

I return to the great luminous bodies, and particularly the sun, which is the principal source of the light and heat which we enjoy on the earth. It will be asked, in the first place, wherein consists the light which the sun is incessantly diffusing through the whole universe, without ever suffering the smallest diminution? The answer is obvious, according to the system which I have been endeavouring to establish. But that of emanation furnishes no satisfactory solution. The whole universe being filled with that extremely subtile and elastic fluid which is called ether, we must suppose, in all the parts of the sun, an incessant agitation, by which every particle is in a constant motion of vibration; and this, by communicating itself to the circumambient ether, excites in that fluid a similar agitation, and is thence transmitted to regions the most remote with the rapidity which I have been describing.

And to keep up the parallel between sound and light, the sun would be in a state similar to that of a bell which should be ringing continually. The particles of the sun must consequently be kept in this incessant agitation, to produce in the ether the undulations which we call rays of light. But it is still no easy matter to explain by what power this agitation in the particles of the sun is constantly kept up, as we observe that a match does not long continue burning, but presently goes out, unless it be supplied with combustible matter. But it must be remarked, that as the sun is a mass many thousand times greater than our whole globe, if it is once thoroughly inflamed, it may continue in that state for several ages without suffering any sensible diminution. Besides, the case is not the same with the sun and our fires and candles, a considerable part of whose substance is dissipated in smoke and exhalations, from which a real waste results. Whereas, though perhaps some particles may be forced from the sun in form of smoke, they cannot remove to a great distance, but speedily fall back into its mass, so that there cannot be any real expenditure to occasion a diminution of his substance.

The only thing of which we are still ignorant respecting this subject is, the power which incessantly maintains all the particles of the sun in this agitation. But as it contains nothing inconsistent with good sense, and as we are under the necessity of acknowledging our ignorance of many other things much less remote than the sun, we ought to be satisfied if our ideas are not involved in contradiction.

21*st June*, 1760.

LETTER XXII.

Elucidations on the Nature of Luminous Bodies, and their Difference from Opaque Bodies illumined.

The sun being a luminous body, whose rays are universally diffused in all directions, you can no longer be at a loss to account for this wonderful phenomenon, which consists in the shaking or vibration with which all the particles of the sun are agitated. The parallel of a bell lends considerable assistance towards the explanation of this fact. But it is obvious that the vibrations produced by light must be much more vehement and rapid than those produced by sound, ether being incomparably more subtile than air. A feeble agitation not being capable of shaking the air so as to produce sound in it, that of a bell, and that of all other sonorous bodies, are too feeble relatively to ether to produce in it the vibration which constitutes light.

You will recollect, that in order to excite a perceptible sound, more than 30, and less than 7552 vibrations must be produced in a second; the air being too subtile to admit of a sensible effect from a sound consisting of less than 30 vibrations in a second, but not sufficiently so to receive one of more than 7552 vibrations in the second. A note higher than this could not be at all heard. It is the same with respect to ether: 7552 vibrations produced in a second could not possibly act upon it, because of its greater subtilty. It requires vibrations much more frequent. An agitation so rapid could not take place but in the minutest particles of bodies which elude our senses. The light of the sun, then, is produced by a very violent agitation, which affects all his infinitely minute particles, each of which must shake many thousands of times every second.

It is a similar agitation which likewise produces the light of the fixed stars, and of all fires, such as candles, tapers, torches, &c., which give us light, and supply the place of the sun during the night. On attentively observing the flame of a wax-light, you will easily perceive, that in the minutest particles, there is a constant and surprising agitation; and I do not apprehend that my system is liable on this side to any contradiction, while that of Newton requires a more enormous agitation, capable of launching the minutest particles with the velocity of 170,000 English miles in a second.

This, then, is the explanation of the nature of bodies luminous of themselves: for there are luminous bodies which are not so immediately, such as the moon and the planets, which are similar to our globe. We see the moon only when and in as far as she is illuminated by the sun; and this is the case of all terrestrial bodies, fires excepted, which have a light of their own. But other bodies, which are denominated opaque, become visible to us only when they are illuminated by some luminous body.

In a very dark night, or in an apartment so closely shut on every side that no light can find admission, to no purpose will you turn your eyes towards the objects which surround you in the dark: you perceive nothing. But the moment a taper is introduced, you immediately see, not the taper only, but the other bodies which were before invisible. We have here, then, a very essential difference between luminous and opaque bodies. I have already employed the term *opaque* to denote bodies which are not transparent; but it comes to almost the same thing; and we must accommodate ourselves to the common modes of expression, though they are not perfectly accurate. Luminous bodies are visible by their own light, and never affect our organs of sight

more than when the darkness is otherwise most profound. Those which I here denominate opaque are rendered visible to us only by means of a light that is foreign to them. We perceive them not while they remain in darkness; but as soon as they are exposed to a luminous body, whose rays strike upon them, they become visible; and they disappear the moment that foreign light is withdrawn. It is not even necessary that the rays of a luminous body should fall upon them immediately; another opaque body, when well illuminated, produces nearly the same effect, but in a feebler manner.

The moon is an excellent instance. We know that the moon is an opaque body; but when she is illuminated by the sun, and we see her during the night, she diffuses a feeble light over all opaque bodies, and renders visible to us those which we could not have perceived without her assistance. Placed in the daytime in an apartment whose aspect is towards the north, and into which, of course, the rays of the sun cannot enter, it is, however, perfectly clear, and I am able to distinguish every object. What can be the cause of this clearness, but that the whole heaven is illuminated by the sun? What we call the azure sky, and, besides, the walls opposite to my apartment, and the other surrounding objects, are likewise illuminated, either immediately by the sun, or mediately by other opaque bodies, exposed to the action of that focus of light; and the light of all these opaque but illuminated bodies, as far as it has admission into my apartment, renders it luminous, and that in proportion as the windows are high, wide, and well placed. The glass is little or no interruption, being, as I have already remarked, a transparent body, which freely transmits the rays of light.

When I completely exclude the light from the apartment by closing the window-shutters, I am reduced to a state of darkness, and discern no object, unless I call for a candle. Here then is an essential difference between luminous and opaque bodies; and likewise a very striking resemblance, namely, that opaque bodies, when illuminated, illuminate other opaque bodies, and produce in this respect nearly the same effect as bodies luminous of themselves. The explanation of this phenomenon has hitherto greatly perplexed philosophers; but I flatter myself that my solution of it has been clear and satisfactory.

24th June, 1760.

LETTER XXIII.

How Opaque Bodies become Visible. Newton's System of the Reflection of Rays proposed.

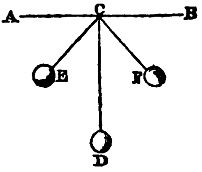
Before I attempt an explanation of the phenomenon of opaque bodies becoming visible when they are illuminated, it must be remarked in general, that we see nothing but by means of the rays which enter into our eyes. When we look at any object whatever, rays issuing from every point of that object, and entering into the eye, paint upon it, if I may use the expression, the image of the object. This is not mere conjecture, but may be demonstrated by experiment. Take, for example, the eye of an ox, or of any animal recently killed, and, after having uncovered the bottom, you find all the objects which were before it painted there. As often then as we see an object, the image of it is painted on the bottom of our eyes; and this is produced by the rays which proceed from the object to us. I shall afterward take occasion to go into a more minute detail on the subject of vision, and explain in what manner the images of objects are formed on the bottom of the eye: let this general remark suffice for the present.

As we see opaque bodies only when they are illuminated, this is a proof that there must proceed from every point of these bodies rays of light which subsist only during the illumination. The moment they are placed in the dark these rays disappear. They are not proper then to opaque bodies; their origin must be sought in the manner in which other bodies illuminate them. And this is the great question, how illumination alone is capable of producing rays on opaque bodies, or of putting them in nearly the same state as luminous bodies are, which, by an agitation in their minutest particles, produce rays of light?

The great *Newton*, and other philosophers who have examined the subject, assign *reflection* as the cause of this phenomenon: it is therefore of the highest importance that you should form a just idea of what is called reflection.

This name is given to the repulsion of one body struck against another, as may be seen in the game of billiards. When the ball is struck against the cushion or ledge of the billiard-table, it recoils again; and this retrograde motion is termed reflection. It is necessary here to attend to a distinction between two cases. Let us suppose A B, *Fig.* 7, to be the ledge of a billiard-table. The first case is this: When you play the ball D perpendicularly against the ledge, in the direction of D C, perpendicular to A B, consequently the adjacent angles A C D and B C D are right angles: in this case the ball will be driven back or reflected in the same line D C. The other case is, when the ball is played obliquely against the ledge, suppose in the line E C, forming with A B an acute angle A C E, this is called the angle of incidence. The ball will in this case be repelled from the ledge

Fig. 7.



in the direction of the line C F, so that this line shall make on the other side, with the ledge B C, an angle B C F, exactly equal to the angle of incidence A C E. This angle B C F, formed by the line in which the ball recoils, is called the angle of reflection. And this law always takes place when a body in motion meets with an obstacle.

A cannon-ball shot against a wall sufficiently strong to resist it is reflected conformably to this law. It extends, in like manner, to sounds which are frequently reflected from certain bodies; and you know that this reflection of sound is called echo. It cannot be doubted, that the same thing frequently takes place with respect to the rays of light. The objects which we see in mirrors are represented to us by the reflection of rays, and every well polished surface reflects the rays of light which fall upon it. It is undoubtedly certain, therefore, that there are cases without number in which the rays that fall on certain bodies are reflected; and philosophers have thence taken occasion to maintain, that opaque bodies are rendered visible by means of reflected rays.

I see just now houses opposite to my windows which are illuminated by the sun. According, then, to the opinion of those philosophers, the rays of the sun falling on the surface of these houses are reflected from them; they enter into my apartment, and render these houses visible to me. In the same manner, if we believe those philosophers, the moon and the planets become visible, and these are unquestionably opaque bodies. The rays of the sun which fall on these bodies, and illuminate the parts which are exposed to them, are reflected, and are thence transmitted to us, just as if the bodies were luminous of themselves. According to this opinion, we see the moon and the planets only by the rays of the sun which they reflect; and you must frequently have heard it affirmed, that the light of the moon is a reflection of the light of the sun. In the same manner, say they, the rays of the sun are reflected by the first opaque bodies which are exposed to them, on other bodies of the same nature, and undergo a series of similar reflections, till they are entirely weakened.

But however plausible this opinion may at first sight appear, it involves so many absurdities when closely examined, that it is absolutely untenable, which I hope to demonstrate, as a preparation for the true solution of this phenomenon.

28*th June*, 1760.

LETTER XXIV

Examination and Refutation of Newton's System.

I affirm, then, that when we see an opaque body illuminated by the sun, it is impossible to maintain that it reflects luminous rays, and that by means of such rays it is rendered visible to us. The example of a mirror, which undoubtedly reflects the rays, and is employed to support this opinion, rather confutes it. The mirror, beyond contradiction, sends back the rays which fall upon it; but when these reflected rays enter into our eyes, what do they represent? You will readily answer, that it is not the mirror, but the objects from which they originally proceeded, and the reflection does nothing else but enable us to see these objects in another place. Besides, we see those objects, not on the surface of the mirror, but rather within it; and it may be said with truth, that the mirror itself remains invisible to us.

But, on looking at an opaque body illuminated by the sun, we do not see in it the image of that glorious orb; we see only the surface of the bodies, with all the variations to be found on them. We perceive, then, a very essential difference between the rays which are reflected from a mirror, and those by means of which opaque bodies are rendered visible.

But there is, besides, another difference equally palpable in the mirror; for on changing the place of the objects, or our own situation, the appearance will always change, and the rays reflected from the mirror will continually represent to our eyes other images, corresponding to the nature and position of the objects, and to the place where we are stationed; but, as I have already said, these reflected rays never represent to us the mirror itself.

Now, let a body be illuminated by the sun, or other bodies, whether luminous or opaque, already illuminated; in whatever manner this body may change its place, or we change ours relatively to it, its appearance is always the same; we see always the same object, and remark in it no change relative to the different circumstances above mentioned. This furnishes a new proof that we do not see opaque bodies by means of the rays reflected from their surface.

An objection will perhaps be started, drawn from the dove's neck, and certain kinds of stuff, which present different objects according as our point of view changes. But this in no respect weakens my conclusion with regard to ordinary opaque bodies, which are not subject to this change. The objection only proves, that these singular objects are endowed with certain qualities; as, for example, that their minuter particles are finely polished, and that a real reflection takes place, besides the usual and ordinary manner in which bodies are rendered visible to us.

Now, it is easy to comprehend, that this reflection must be clearly distinguished from the manner in which ordinary opaque bodies are illuminated.

Finally, the rays reflected from a mirror always represent to us, likewise, the colours of the bodies from which they originally proceed; and the mirror which reflects makes no change in this respect. One opaque body, illuminated by any other body, in whatever manner, always presents the same colours; and every body may be said to have its proper colour. This circumstance absolutely overturns the opinion of all those who maintain that we see opaque bodies by means of the rays which their surface reflects.

Putting together all the reasons which I have now submitted to your consideration, there can be no hesitation in pronouncing that this opinion is totally untenable in philosophy, or rather, in physics. I cannot, however, flatter myself with the hope, that philosophers, wedded to opinions once adopted, should yield to these reasons. But the naturalist, who is more nearly related to the mathematician, will have less difficulty in resigning an opinion overthrown by reasons so convincing. You will again recollect what Cicero has said on this subject: That nothing so absurd can be conceived as not to be supported by some philosopher. In fact, however strange the system which I have been refuting may appear to you, it has hitherto been propagated and defended with much warmth.

It is impossible to say to what a degree the difficulties and contradictions which I have been endeavouring to expose were unknown to, or overlooked by, the partisans of this system. The great *Newton* himself strongly felt their force; but as he rested in a very untenable idea respecting the propagation of light, it is not to be wondered at that he should overlook these great difficulties; and, in general, depth of understanding does not always prevent a man from falling into absurdity in supporting an opinion once embraced.

But if this system, that opaque bodies are rendered visible by reflected rays, be false, say its partisans, what then is the true one? They even think it impossible to imagine another explanation of this phenomenon. It is, besides, rather hard and humiliating for a philosopher to acknowledge ignorance of any subject whatever. He would rather maintain the grossest absurdities; especially if he possesses the secret of involving them in mysterious terms, which no one is capable of comprehending. For in this case the vulgar are the more disposed to admire the learned; taking it for granted that what is obscurity to others is perfectly clear to them. We ought always to exercise a little mistrust when very sublime knowledge is pretended to—knowledge too sublime to be rendered intelligible. I hope I shall be able to explain the phenomenon in question, in such a way as to remove every difficulty.

1st July, 1760.

LETTER XXV.

A different Explanation of the Manner in which Opaque Bodies illuminated become visible.

All the phenomena of opaque bodies, which I have unfolded in the preceding Letter, incontestably demonstrate that when we see an opaque body illuminated, it is not by rays reflected from its surface that it becomes visible, but because its minuter particles are in an agitation similar to that of the minuter particles of luminous bodies; with this difference, however, that the agitation in opaque bodies is far from being so strong as in bodies luminous of themselves; for an opaque body, however much illuminated, never makes on the eye an impression so lively as luminous bodies do.

As we see the opaque bodies themselves, but by no means the images of the luminous bodies which enlighten them, as must be the case if we saw them by the reflection of their surface, it must follow that the rays emitted by opaque bodies are proper to them, just as the rays of a luminous body are peculiar to itself. As long as an opaque body is illuminated, the minuter particles of its surface are in a state of agitation proper to produce in the ether

a motion of vibration such as is necessary for forming rays, and for painting in our eyes the image of the body from which they proceed. For this effect, rays must be diffused from every point of the surface, in all directions—as experience evidently confirms. For, from whatever side we look at an opaque body, we see it equally in all its points; from which it follows that every point emits rays in all directions. This circumstance essentially distinguishes these rays from such as are reflected, whose direction is always determined by that of the rays of incidence; so that if the incident rays proceed from one single quarter, say the sun, the reflected rays can follow only one single direction.

It must be admitted, then, that when an opaque body is illuminated, all the particles on its surface are put in a certain agitation, which produces rays, as is the case with bodies luminous of themselves. This agitation, likewise, is stronger in proportion as the light of the illuminating body is more intense. Thus the same body, exposed to the sun, is agitated much more violently than if, in a room, it were illuminated only by daylight; or in the night-time by a taper, or by the moon. In the first case, its image is painted with much greater vivacity on the bottom of the eye than in the others, especially the last; the light of the moon being scarcely sufficient to enable us to distinguish, or to read, writing of a large size. And when the opaque body is conveyed into a close room, or into the dark, nothing is then to be seen—a certain proof that the agitation in its parts has entirely ceased, and that they are now in a state of rest.

In this, therefore, consists the nature of opaque bodies; their particles are of themselves at rest, or at least destitute of the agitation necessary to produce light. But these same particles are so disposed, that when illuminated, or struck with rays of light, they are immediately put into a certain agita-

tion, or motion of vibration, proper to produce rays; and the more intense the light is which illuminates these bodies, the more violent also is this agitation. As long as an opaque body is illuminated, it is in the same state as luminous bodies; its particles are agitated in the same manner, and are capable of exciting, of themselves, rays in the ether; with this difference, that the agitation kept up in luminous bodies by an intrinsic force subsists always of itself; whereas in opaque bodies this agitation is only momentary, and produced by the motion of the light which illuminates them.

This explanation is consistent with every phenomenon, and labours under none of the difficulties which determined us to abandon the other, namely, that founded on reflection. Whoever will take the trouble candidly to weigh all these reasons must admit their force. But a very great difficulty still remains to be solved: how comes it that illumination simply can put the particles of an opaque body into an agitation capable of producing rays: and that this agitation should always continue nearly the same, whatever difference there may be in the illumination?

I acknowledge, that were it impossible to answer this question, it would be a great defect in my theory, though it would not amount to a complete refutation; for it contains nothing contradictory. Supposing I were ignorant how illumination produces an agitation in the particles of opaque bodies, this would only prove that the theory is incomplete; and till it is demonstrated to be absolutely impossible that illumination should produce this effect, my system must subsist. But I shall endeavour to supply this defect, by showing you how illumination agitates the minutest particles of bodies.

5th July, 1760.

LETTER XXVI.

Continuation of the same Subject.

I HAVE undertaken to show how the illumination of an opaque body must produce, in its minutest particles, an agitation proper to excite the rays of light, which render that same opaque body visible. The parallel between sound and light, which differ only in respect of less and more, light being the same thing relatively to ether that sound is relatively to air—this parallel, I say, will enable me to fulfil my engagement. Luminous bodies must be compared to musical instruments actually in a state of vibration. It is a matter of indifference whether this be the effect of an intrinsic or of a foreign power; it is sufficient for my purpose that sound is emitted. Opaque bodies, as long as they are not illuminated, must be compared to musical instruments not in use; or, if you will, to strings which emit no sound till they are touched.

The question, then, being transferred from light to sound, is resolved into this, Whether it be possible for the string of an instrument in a state of rest, when brought within the sphere of activity of the sound of instruments in a state of vibration, to receive, in certain circumstances, some agitation, and emit sound, without being touched? Now this is confirmed by daily experience. If you take the trouble, during a concert, to attend to a particular string in proper tune, you will observe that string sometimes to tremble without having been touched, and it will emit the same sound as if it had been immediately put into vibration. This experiment will succeed still better, if the instruments strike the same note with the string. Consider attentively the strings of a harpsichord not played upon, while a violin strikes the note *a*, for example, and you will observe on the harpsichord the string of the same note begin sensibly to tremble, and even to emit sound, without having been touched; some other chords will likewise be agitated, particularly those which are distant an octave, a fifth, and even a third, provided the instrument be perfectly in tune.

This phenomenon is well known to musicians; and Mr. Rameau, one of the most celebrated French composers, established his principles of harmony upon it. He maintains that octaves, fifths, and thirds must be considered as consonances, because one chord is agitated by the sound only of another chord which is in unison, or an octave, a fifth, or a third from the first. But it must be admitted that the principles of harmony are so well established by the simplicity of the relations which sounds have to each other, that they have no need of a new confirmation. In truth, the phenomenon observed by Mr. Rameau is a very natural consequence from the principles of harmony.

To render this more sensible, let us attend to two chords wound up to unison; on striking the one, the other will begin of itself to tremble, and will emit its sound. The reason is abundantly clear: for as a chord communicates to the air by its trembling a motion of vibration similar to its own, the air, agitated by this motion of vibration, must reciprocally make the chord tremble, provided that by its degree of tension it be susceptible of this motion. The air, being put into vibration, strikes the chord ever so little at every reverberation, and the repetition of strokes soon impresses on the chord a sensible motion; because the vibrations to which it is disposed by its tension accord with those of the air. If the number of vibrations in the air is the half, or the third, or any other whose relation is sufficiently simple, the chord does not receive a new impulse at every vibration, as in the preceding case, but only at the second, or the third, or the fourth, which will continue to increase its tremulous motion, but less than in the first case.

But if the vibrations of the air have not any simple relation with that which corresponds to the chord, the agitation of that fluid will produce no effect whatever upon it; the vibrations of the chord, if there be any, not corresponding to those of the fluid, the following impulsions of the air destroy for the most part the effect which the first might have produced; and this is completely confirmed by experience. Thus, when a chord is shaken by a sound, that sound must, in order to its being perceptible, be precisely the same with that of the chord. Other sounds which have a consonance with that of the chord will produce, it is true, a similar but less sensible effect, and dissonances will produce none at all. This phenomenon takes place not only in musical strings, but in all sonorous bodies whatever. One bell will resound by the noise only of another bell which is in unison with it, or at the distance of an octave, a fifth, or a third.

The instance of a person who could break glasses by his voice further confirms what I have advanced. When a glass was presented to him, by striking it he found out the note; he then began to squall in unison, and the glass immediately caught the vibration; proceeding to give to his voice all the force he was able, always preserving the unison, the vibration of the glass became at length so violent that it broke. It is confirmed, then, by experience, that a chord and every other sonorous body is put into vibration by its kindred sound. The same phenomenon must take place with regard to opaque bodies, of which the minuter particles may be put into a state of agitation by illumination only—which is the question I proposed to solve. The following Letter will contain a more ample discussion of it.

8th July, 1760.

LETTER XXVII.

Conclusion: Clearness and Colour of Opaque Bodies illuminated.

After what has been just submitted to your consideration, you will no longer be surprised that an opaque body is capable of receiving from illumination alone an agitation in its particles similar to that of the particles of luminous bodies, and which gives them the property of producing rays that render them visible. Thus the great objection to my explanation of the visibility of opaque bodies is happily removed; while the other theory, founded on the reflection of rays, has to encounter difficulties which grow in proportion as you attempt to make a more direct application of them to known phenomena.

It is then an established truth, that the particles of the surfaces of all bodies which we see undergo an agitation similar to that of a chord in vibration, but their vibrations are much more rapid; whether it be that this agitation is the effect of an intrinsic force, as in bodies luminous of themselves, or whether it be produced by the rays of light which fall upon the bodies, that is to say, by illumination, as is the case in opaque bodies. It is false, then, that the moon, being an opaque body, reflects the rays of the sun, and that by means of this reflected light she is rendered visible to us, as is commonly understood. But the rays of the sun, falling on the surface of the moon, excite in its particles a concussion, from which result the rays of the moon; and these, entering into our eyes, paint its image there; it is the same with the other planets, and with all opaque bodies. This agitation of opaque bodies, when illumined, lasts only during the illumination which is the cause of it; and

as soon as an opaque body ceases to be illumined, it ceases to be visible.

But is it not possible that this agitation, once impressed on the particles of an opaque body, may be for some time kept up, as we see that a string once struck frequently continues to vibrate, though no new impression be made upon it? I do not pretend to deny the fact: I even believe that we have examples of it in those substances which Mr. Margraff presented to you, and which, once illumined, preserve their light for some time, though conveyed into a dark room. This, however, is an extraordinary case, the vibration of the minuter particles disappearing in all other bodies with the illumination which occasioned it. But this explanation, which thus far is perfectly self-consistent, leads me forward to researches of still greater importance.

It is undoubtedly certain, that we find an infinite difference between the particles of opaque bodies, according to the variety of the bodies themselves. Some will be more susceptible of vibrations, and others less, and others finally not at all so. This difference in bodies occurs but too evidently. One, whose particles easily receive the impression of the rays which strike it, appears to us brilliant; another, on the contrary, in which the rays scarcely produce any agitation, cannot appear luminous. Among several bodies, equally illumined, you will always remark a great difference, some being more brilliant than others. But there is besides another and a very remarkable difference between the particles of opaque bodies, respecting the number of vibrations which each of them, being agitated, will make in a certain time.

I have already observed, that this number must always be very great, and that the subtilty of ether is such as to require many thousands in a second. But the difference here may be endless, if some particles, for example, should make 10,000 vibrations in a second, and others 11,000, 12,000, 13,000, according to the smallness, the tension, and the elasticity of each, as in the case of musical chords, in which the number of vibrations given in a second may be varied without end; and thence it is I have deduced the difference of high and low notes. As this difference is essential in sounds, and as the ear is affected by it in a manner so particular as to render it the foundation of the whole theory of music, it cannot be called in question that a similar difference in the frequency of the vibrations of rays of light must produce a variation as particular in vision. If, for example, a particle makes 10,000 vibrations in a second, and produces rays of the same species, the rays which enter into the eye will strike the nerves of that organ 10,000 times in a second; and this effect, as well as the sensation, must be totally different from those produced by a different particle which should make more or less vibrations in a second. There will be in vision a difference similar to that which the ear perceives on hearing sharp or flat notes.

You will no doubt be desirous to know into what this difference in vision is to be resolved; and what different sensations correspond to the number, greater or less, of the vibrations produced in every body during a second. I have the honour of informing you, that diversity of colours is occasioned by this difference; and that difference of colour is to the organ of vision what sharp or flat sounds are to the ear. We have resolved, therefore, without going after it, the important inquiry respecting the nature of colours, which has long employed the attention of the greatest philosophers. Some of them have called it a modification of light absolutely unknown to us. *Descartes* maintains, that colours are only a certain mixture of light and shade. *Newton* accounts for difference of colour by tracing it up to the rays of the sun; which, according to him, are a

real emanation, whose matter may be more or less subtile; and thence settles the rays of all the colours, as red, yellow, green, blue, violet, &c.

But as this system falls to pieces of itself, all that has been said respecting colours conveys no information; and you are now clearly sensible, that the nature of each colour consists in the number of vibrations produced in a certain time, by the particles which present them to the eye.

12*th July*, 1760.

LETTER XXVIII.

Nature of Colours in particular.

THE ignorance which prevailed respecting the true nature of colours has occasioned frequent and violent disputes among philosophers; each of whom made an attempt to shine, by maintaining a peculiar opinion on the subject. The system which made colours to reside in the bodies themselves appeared to them too vulgar and too little worthy of a philosopher, who ought always to soar above the multitude. Because the clown imagines that one body is red, another blue, and another green, the philosopher could not distinguish himself better than by maintaining the contrary; and he accordingly affirms that there is nothing real in colours, and that there is nothing in bodies relative to them.

The Newtonians make colours to consist in rays only, which they distinguish into *red*, *yellow*, *green*, *blue*, *indigo*, and *violet*; and they tell us that a body appears of such and such a colour when it reflects rays of that species. Others, to whom this opinion seemed absurd, pretend that colours exist only in ourselves. This is an admirable way to conceal ignorance; the vulgar might otherwise believe that the scholar was not better acquainted with the nature

of colours than themselves. But you will readily perceive that these affected refinements are mere cavil. Every simple colour (in order to distinguish from compound colours) depends on a certain number of vibrations, which are performed in a certain time; so that this number of vibrations, made in a second, determines the red colour, another the yellow, another the green, another the blue, and another the violet, which are the simple colours represented to us in the rainbow.

If, then, the particles of the surface of certain bodies are disposed in such a manner, that being agitated they make in a second as many vibrations as are necessary to produce, for example, the red colour, I call such a body red, just as the clown does; and I see nothing like a reason for deviating from the common mode of expression. And rays which make such a number of vibrations in a second may, with equal propriety, be denominated red rays; and finally, when the optic nerve is affected by these same rays, and receives from them a number of impulsions, sensibly equal, in a second, we receive the sensation of the red colour. Here every thing is clear; and I see no necessity for introducing dark and mysterious phrases, which really mean nothing.

The parallel between sound and light is so perfect, that it holds even in the minutest circumstances. When I produced the phenomenon of a musical chord, which may be excited into vibration by the resonance only of certain sounds, you will please to recollect, that the one which gives the unison of the chord in question is the most proper to shake it, and that other sounds affect it only in proportion as they are in consonance with it. It is exactly the same as to light and colours; for the different colours correspond to the different musical sounds.

In order to display this phenomenon, which completely confirms my assertion, let a dark room be

provided; make a small aperture in one of the shutters; before which, at some distance, place a body of a certain colour, say a piece of red cloth, so that when it is illumined its rays may enter by the aperture into the darkened room. The rays thus transmitted into the room will be red, all other light being excluded; and if you hold on the inside of the room, opposite to the aperture, a piece of cloth of the same colour, it will be perfectly illumined, and its red colour appear very brilliant; but if you substitute in its place a piece of green cloth, it will remain obscure, and you will hardly see any thing of its colour. If you place on the outside, before the aperture, a piece of green cloth, that within the chamber will be perfectly illumined by the rays of the first, and its green colour appear very lively. The same holds good as to all other colours: and I do not imagine that a more convincing demonstration of the truth of my system can be demanded.

We learn from it, that in order to illuminate a body of a certain colour, it is necessary that the rays which fall upon it should have the same colour; those of a different colour not being capable of agitating the particles of that body. This is further confirmed by a well-known experiment. When the spirit of wine is set on fire in a room, you know that the flame of spirit of wine is blue, that it produces only blue rays, and that every person in the room appears very pale—their faces, though painted ever so deep, have the aspect of death. The reason is evident; the blue rays not being capable of exciting or putting in motion the red colour of the face, you see on it only a feeble and bluish colour; but if one of the company is dressed in blue, such dress will appear uncommonly brilliant. Now the rays of the sun, those of a wax taper, or of a common candle, illuminate all bodies almost equally; from whence it is concluded that the rays of the sun contain all colours at once, though he himself appears yellowish, In truth, when you admit into a dark room the rays of all the simple colours, red, yellow, green, blue, and violet, in nearly equal quantities, and blend them, they represent a whitish colour. The same experiment is made with various powders, coloured in like manner; on being mixed together, a whitish colour is the result. Hence it is concluded, that white is not a simple colour, but that it is rather a compound of all the simple colours; accordingly we see that white is adapted to the reception of all colours. As to black, it is not properly a colour. Every body is black when its particles are such that it can receive no motion of vibration, or when it cannot produce rays. The want of rays, therefore, produces the sensation of that colour; and the more particles there are found in any body not susceptible of any motion of vibration on its surface, the more blackish and obscure it appears.*

15th July, 1760.

LETTER XXIX.

Transparency of Bodies relative to the Transmission of Rays.

I HAVE already remarked that there are bodies, such as glass, water, and especially air, which transmit the rays of light, and on account of this property are denominated pellucid or diaphanous. The ether, however, is the medium in which the rays of light are formed, to which this property most intimately appertains; and other transparent bodies are

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* A strong objection to the theory of Euler, in relation to the cause of colour, arises from the fact that so slight a modification of the surface of a body as a coat of paint should so change its quality of vibration as to convert it from one which vibrates, so easily as to emit a bright white light, to one which will not vibrate at all, and which, therefore, appears quite black. We are not aware that such simple changes of surface produce much effect on sound.—*Am. Ed.*

endowed with it only by means of the ether which they contain, and with which they are so blended that the agitations excited by the light may be communicated farther without being interrupted in their progress. But this transmission is never performed so freely as in the pure ether, though it always loses something; and this in proportion as the transparent body is more or less gross. The grossness may even become so considerable that the light shall be wholly lost in it; and then the body is no longer transparent. Thus, though glass be a transparent body, a great lump of glass several feet thick is not so. In like manner, however pure the water of a river may be, you cannot see the bottom where it is very deep, though you can very easily see it where it is shallow.

Transparency, then, is a property of bodies relative only to their thickness; and when this property is ascribed to glass, to water, &c., it must always be understood with this restriction, that these bodies are not too gross; and that to every species there is a certain measure of thickness beyond which the body ceases to be transparent. There is not one opaque body, on the contrary, which may not itself become transparent, if reduced to a plate extremely fine. Thus, though gold is not transparent, gold leaf is so; and on examining the minuter particles of all bodies with a microscope they are found to be transparent. It may then be with truth affirmed that all bodies are transparent when reduced to a certain degree of fineness; and that no one is so when too gross.

In common language we denominate transparent the bodies which preserve this quality to a certain degree of thickness, though they lose it when they go beyond that bound. But with respect to ether, it is of its own nature perfectly transparent, and its extent diminishes not this quality in the smallest degree. The prodigious distance of the fixed stars prevents not their rays from being transmitted to us. But though our air appears to be of a perfect transparency, if it extended as far as the moon, that transparency would be entirely lost, and would prevent every ray of the sun, and of the other heavenly bodies, from penetrating to us. We should then be involved in Egyptian darkness.

The reason of it is evident, and we remark the same thing in sound, whose resemblance to light is confirmed in every respect. Air is the most proper medium for the propagation of sound; but the agitations excited in the air are capable of shaking also the particles of all bodies: and these again putting in motion the interior particles, finally transmit the vibration through the substance of all bodies, unless they be too thick. There are bodies, then, which, relatively to sound, are the same thing which transparent bodies are relatively to light; and all bodies have this property with relation to sound, provided they are not too thick. When you are in your apartment, you can hear almost every thing that passes in the antechamber, though the doors are closely shut, because the agitation of the air in the antechamber communicates itself to the partitions, and penetrates through them into the inner apartment, with some loss, however. Were the partition removed, you would undoubtedly hear more distinctly. Now the thicker the walls are the more of its force does the sound lose in piercing through them; and the walls may be made so thick that nothing could be heard from without, unless it were some terrible noise, such as a discharge of cannon.

This leads me forward to a new remark, that very powerful sounds may be heard through walls which are impenetrable to sounds more feeble; and, consequently, in order to form a judgment whether a wall is capable of transmitting sounds, it is necessary to take into the account, not only the thickness of the wall, but likewise the strength of the sound.

If the sound is very feeble, a very thin wall is sufficient to stop it; though a louder could find an easy transmission. The same thing holds as to bodies which are permeable only to a very strong light. Objects not very brilliant are invisible through a glass blackened with smoke, but the rays of the sun force themselves through it, and it transmits perfectly well the image of that luminary. Astronomers employ this method to observe him; for without such precaution he would dazzle the eye. And when you happen to be in a dark room, with an aperture in the shutter exposed to the sun, in vain will you attempt to exclude the light by opposing your hand to the aperture; the rays of the sun will force themselves through.

It is perceivable, at the same time, that the light of the sun loses much of its lustre in passing through a body which, relatively to other objects, is not itself transparent. But a very strong light may lose much of its lustre before it is entirely extinguished, while a feebler light is lost at once. A piece of very thick glass, then, will not be transparent with respect to objects less brilliant, though the sun may be visible through it.

These remarks on transparent bodies lead me to the theory of refraction, of which you have frequently heard, and which I shall endeavour to place in its proper light.

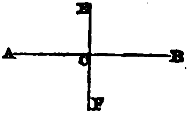
18*th July*, 1760.

LETTER XXX.

Of the Transmission of Rays of Light, through transparent Mediums, and their Refraction.

As long as light moves in the same medium, whether it be ether, air, or any other transparent body, the propagation proceeds in straight lines, denominated rays, as they diverge from the luminous point, in all directions, like the radii of a circle or a globe issuing from the centre. In the system of emanation the particles darted from luminous bodies move in straight lines: the same thing holds in that which I have had the honour of proposing, in which the agitations are communicated in straight lines, as the sound of a bell is transmitted in a straight line, by which also we judge from what quarter the sound comes; the rays in both systems, then, are represented by straight lines, as long as they pass through the same transparent medium; but they may undergo some bending, in passing from one to another; and this bending is called the *refraction* of the rays of light, the knowledge of which is necessary to account for many phenomena. I proceed, therefore, to lay down the principles, in conformity to which refraction takes place.

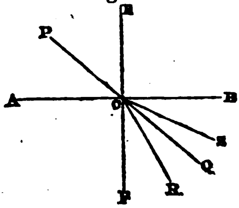
Fig. 8.



It is an invariable law, that when a ray, such as E C, *Fig.* 8, falls perpendicularly on the surface A B of another medium, it continues its progress in the same straight line extended, as C F; it will, in this case, undergo no bending or refraction. If, then, E C is a ray of the sun falling perpendicularly on the surface A B of water, or of glass, it will enter it in the same direction, and continues its progress in the line C F, which is likewise perpendicular to the surface A B, so that E F shall be in one and the same straight line. This is the only case in which there is no refraction. But as often as the ray does not fall perpendicularly on the surface of another transparent body, it does not pursue its progress in the same straight line; it recedes less or more from it, and undergoes a refraction.

Let P C, *Fig*. 9, be a ray, falling obliquely on the surface A B of another transparent medium. On entering into this medium, it will not continue its progress in the direction of the line C Q, which is the line P C produced; but will recede from it in the direction of the line C R, or C S. It will undergo, then, at the point C, a bending, which we call refraction, which depends partly on the difference of the two mediums, and partly on the obliquity of the direction of the ray P C.

Fig. 9.



In order to comprehend the laws of this bending, it is necessary to explain certain terms employed in treating this subject.

1st, The surface A B, which separates the two mediums, that from which the ray comes, and that into which it enters, is called the *refracting surface*. 2dly, The ray P C, which falls upon it, is called the *incident ray*; and, 3dly, the ray C R, or C S, which pursues, in the other medium, a course different from C Q, is called the *broken* or *refracted ray*. And having drawn through the surface A B the perpendicular line E C F, we call, 4thly, the angle P C E, formed by the incident ray P C with the perpendicular E C, *the angle of incidence*; and, 5thly, the angle R C F, or S C F, formed by the refracted C R or C S, with the perpendicular C F, is called the *angle of refraction*.

Therefore, because of the bending which of light undergoes, the angle of refraction equal to the angle of incidence P C E; fo ducing the line P C to Q, the angles P C E and being vertical, are equal to each other (Euclid s E ments, Book I., Prob. 15), as you will easily reco lect. The angle Q C F, then, is equal to the angle o incidence P C E; therefore the angle of refractio R C F or S C F is greater or less. There are, then, only two cases which can exist; the one, in which the refracted ray being C R, the angle of refraction R C F is less than the angle of incidence P C E; and the other, in which the refracted ray being C S, the angle of refraction is greater than the angle of incidence P C E. In the former case, we say, that the ray C R approaches the perpendicular C F; and in the other, that the refracted ray C S recedes or deviates from the perpendicular.

It is necessary, then, to inquire in what cases the one or the other of these changes will take place. And we shall find that this phenomenon depends on the difference of the density of the two mediums, or because the rays are transmitted with more or less difficulty through each of them. To prove this, it must be recollected that ether is of all mediums the most rare, and that through which rays are transmitted without the slightest resistance. After it the other common transparent mediums are thus arranged: air, water, glass; thus glass is a medium more dense than water, water than air, and air than ether.

This being laid down, we have only to attend to these two general rules: 1st, When rays pass from a medium less dense into one which is more so, the refracted ray approaches the more to the perpendicular. This is the case in which the incident ray being P C, the refracted ray is C R. 2dly, When the rays pass from a medium more dense to one less so, the refracted ray recedes from the perpendicular. This is the case in which the incident ray being

P C, the refracted ray is C S. Now, this bending is greater or less according as the two mediums differ in respect of density. Thus rays in passing from air into glass undergo a greater refraction than when they pass from air into water; in both cases, however, the refracted rays approach the perpendicular. In like manner, rays passing from glass into air undergo a greater refraction than when they pass from water into air; but in these cases the refracted ray recedes from the perpendicular.

Finally, it must likewise be remarked that the difference between the angle of incidence and the angle of refraction is so much greater, as the angle of incidence is greater; or, as the incident ray recedes farther from the perpendicular, the greater will be the bending or refraction of the ray. A relation between all these angles exists, and is determinable by geometry; but it is not now necessary to enter into the detail. What has been already said is sufficient for understanding what I have further to propose on the subject.*

22*d July*, 1760.

LETTER XXXI.

Refraction of Rays of different Colours.

You have seen that when a ray of light passes obliquely from one transparent medium to another, it undergoes a bending, which is called refraction, and that the refraction depends on the obliquity of the incidence and the density of the mediums. I must now call upon you to remark, that diversity of colours occasions likewise a small variety in the refraction. This arises undoubtedly from the circumstance that the rays which excite in us the sensations of different colours perform unequal numbers of vibrations in the same times, and that they differ among themselves, in the same manner as sharper or flatter sounds do. Thus, it is observable that rays of *red* undergo the least bending or refraction; after them come the *orange*; the *yellow*, the *green*, the *blue*, and the *violet* follow in order; so that violet-coloured rays undergo the greatest refraction; it being always understood that the obliquity of the incidence and the density of the mediums are the same. Hence it is concluded that rays of different colours have not the same refrangibility; that the *red* are the least, and the *violet* the most refrangible.

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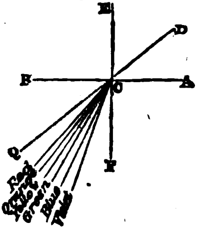
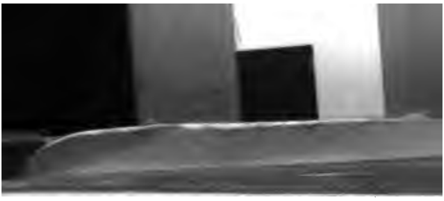
* The phenomenon of refraction furnishes one of the strongholds of Sir Isaac Newton in defence of the theory of emanations. The directions of a ray of light in passing from one medium to another of a different density conforms to the general law of attraction, by which a mass of matter attracts towards itself material particles of great mobility and extreme lightness.—*Am. Ed.*

Fig. 10.



If, then, P C *Fig.* 10, is a ray passing, for example, from *air* into *glass*; the angle of incidence being P C E, the refracted ray will approach the perpendicular C F; and if the ray be *red*, the refracted ray will be in the direction C—*red*; if it be *orange*, the refracted ray will be C—*orange*; and so of the rest, as may be seen in the figure. All these rays deviate from the line C Q, which is P C produced, towards the perpendicular C F; but the red ray deviates the least from C Q, or undergoes the least refraction, and the violet recedes the farthest from C Q, and undergoes the greatest refraction.

Now if P C is a ray of the sun, it produces at once all the coloured rays indicated in the figure; and if a piece of white paper is placed to receive them, you will in effect see all these colours; hence it is affirmed, that every ray of the sun contains at once all the simple colours. The same thing happens if



P C is a ray of white, or if it proceeds from a white body. We see all the colours produced from it by refraction, whence it is concluded that white is an assemblage of all the simple colours, as we formerly showed. In truth, we have only to collect all these coloured rays into a single point, and the colour of white will be the result.

It is thus we discover what are the simple colours. Refraction determines them incontestably. In following the order which it presents, they are these: 1, red; 2, orange; 3, yellow; 4, green; 5, blue; 6, violet.[*] But it must not be imagined that there are but six; for as difference of colours arises from the number of vibrations which rays perform in one and the same time, or rather the undulations which produce them, it is clear that the intermediate numbers equally give simple colours. But we want names by which to designate these colours; for between *yellow* and *green* we evidently perceive intermediate colours, for which we have no separate names.

In conformity to the same laws are produced the colours visible in the *rainbow*. The rays of the sun, in passing through the drops of water which float through the air, are by them reflected and refracted, and the refraction decompounds them into the simple colours. You must undoubtedly have remarked, that these colours follow each other in the same order in the rainbow, the *red*, *orange*, *yellow*, *green*, *blue*, and *violet*; but we discover in it also all the intermediate colours, as shades of one colour to another; and had we more names to distinguish these degrees, we might find more of them from the one extremity to the other. A more copious language may perhaps enable another nation actually to reckon a greater number of different colours: and another, it may be, cannot reckon so many; if, for example, it wants a term to express what we call orange. Some to these add *purple*, which we perceive at the extremity of the red, but which others comprehend under the same name with red.

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[*] When the beam of light is very small, Dr. Wollaston found that there were only *four* colours, viz. *red*, *yellowish-green*, *blue*, and *violet*, in the proportions 16, 23, 36, and 25. These proportions, however, vary with the inclination of the incident ray, and also with the nature of the refracting body, of which the prism is formed. The power of any body to produce colour by a separation of the coloured rays is called its *dispersive power*, which does not depend upon its *refractive power*. See the *Edinburgh Encyclopædia*, Art. Optics, vol. xv. p. 485, 541.—*Ed.*

C.	D.	E.	F.	G.	A.	B.
Purple.	Red.	Orange.	Yellow.	Green.	Blue.	Violet.

These colours may be compared to the notes of an octave, as I have done here, because the relations of colours, as well as those of sound, may be expressed by numbers. There is even an appearance, that by straining the violet a little more, you may come round to a new purple, just as in rising from sound to sound, on going beyond B you come round to *c*, which is the octave above C. And as in music we give to these two notes the same name, because of their resemblance, the same thing takes place in colours, which, after having risen through the intervals of an octave, resume the same names; or, if you will, two colours, like two sounds, in which the number of vibrations in the one is precisely the double of the other, pass for the same, and bear the same name.

On this principle it was that Father *Castel*, in France, contrived a species of music of colours. He constructed a harpsichord, of which every key displayed a substance of a certain colour; and he pretended that this harpsichord, if skilfully touched, would present a most agreeable spectacle to the eye. He gave it the name of the *Ocular Harpsichord*,* and you must undoubtedly have heard it talked of. For my part, painting rather seems to be that to the eye which music is to the ear; and I greatly doubt whether the representation of several shreds of cloth of different colours could be very agreeable.

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* An account of Father *Castel's* Ocular Harpsichord will be found in Dr. Brewster's *Treatise on the Kaleidoscope*, p. 131.—*Ed.*

27th July, 1760.

LETTER XXXII.

Of the Azure Colour of the Heavens.

You have just seen that the cause of the visibility of objects is a motion of vibration extremely rapid, by which the minuter particles of their surfaces are agitated, and that the frequency of these vibrations determines the colour.

It is the same thing whether these particles be agitated by an intrinsic force, as in luminous bodies, or whether they receive their agitation from illumination, or from foreign rays, by which they are illumined, as in opaque bodies. The frequency or rapidity of the vibrations depends on the grossness of these particles, and on their elasticity, as that of the vibrations of a musical string depends on its thickness and degree of tension; thus, as long as the particles of a body preserve the same elasticity, they represent the same colour, as the leaves of a plant preserve a green colour as long as they are fresh; but when they begin to dry, the difference of elasticity which then takes place produces likewise a different colour. This subject I have already discussed. I now proceed to explain why the heavens appear to us of a blue colour in the daytime.

On observing this phenomenon with a vulgar eye, it would appear that we are surrounded by a prodigious vault of azure, as painters represent the sky on a ceiling. I have no occasion to undeceive you respecting this prejudice: a small degree of reflection is sufficient to make you comprehend that the heavens are not an azure vault, to which the stars are affixed like so many luminous studs. You are perfectly convinced that the stars are immense bodies, at inconceivable distances from us, and which move freely through a space almost void, or which is filled only by that subtile matter called ether. And I will show you that this phenomenon is to be ascribed to our atmosphere, which is not perfectly transparent.

Were it possible to rise higher and higher above the surface of the earth, the air would become gradually more and more rare, till it ceased to assist respiration, and would at length entirely cease; we should then have reached the region of pure ether. Accordingly, in proportion as we ascend on mountains, the mercury in the barometer continues to fall, because the atmosphere becomes lighter and lighter; and then likewise it is remarked, that the azure colour of the heavens becomes fainter; and were it possible to mount into pure ether, it would entirely disappear: on looking upward, we should see nothing at all, and the heavens would appear black as night; for where no ray of light can reach us, every thing wears the appearance of black.

There is good reason, then, for asking, Why the heavens appear to be blue? This phenomenon could not exist were air a perfectly transparent medium, as ether is: in that case, we should receive from above no other rays but those of the stars: but the lustre of daylight is so great that the feeble light of the stars is absorbed by it. You could not perceive the flame of a taper in the day-time at any considerable distance; but that same flame in the night would appear very brilliant at much greater distances. This clearly proves, that we must look for the cause of the azure colour of the heavens in the want of transparency in the air. The air is loaded with a great quantity of small particles, which are

not perfectly transparent, but which, being illuminated by the rays of the sun, receive from them a motion of vibration, which produces new rays proper to these particles; or else they are opaque, and become visible to us from being illumined.*

Now, the colour of these particles is blue; and this explains the phenomenon: the air contains a great quantity of small blue particles: or it may be said that its minuter particles are bluish, but of a colour extremely delicate, and which becomes sensible to us only in an enormous mass of air. Thus, in a room, we perceive nothing of this blue; but when the bluish rays of the whole atmosphere penetrate our eyes at once, however delicate the colour of each singly, their totality may produce a very deep colour.

This is confirmed by another phenomenon, with which you must be well acquainted. If you look at a forest, from a moderate distance, it appears quite green; but in proportion as your distance increases, it acquires a bluish cast, and this gradually becomes deeper and deeper. The forests on the mountains of Hartz, which may be seen from Magdeburg, appear thence to be blue, but viewed from Halberstadt, they are green. The great extent of air between Magdeburg and these mountains is the reason of it. However delicate or rare the bluish particles of the air may be, there is such a prodigious quantity of them in that interval, the rays of which enter into the eye at once, that they represent a tolerable deep blue.†

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* That the air is loaded with particles not perfectly transparent, and that the vibration of these particles is the cause of the blueness of the sky, must be considered merely as an hypothesis. When the atmosphere is the most transparent, and most free, as it would seem, from foreign opaque particles, the sky appears of the deepest blue. This beautiful cerulean hue doubtless arises from the reflection of the bluer ray from the mass of the atmosphere itself.—*Am. Ed.*

† When the purest spring water is placed in a large reservoir lined with something white, its tint is invariably of a blue colour. Hence arises the blue colour of masses of transparent ice, in the glaciers of

We remark a similar phenomenon in a fog, when the air is loaded with a great quantity of opaque particles of a whitish colour. On looking only to a small distance, you scarcely perceive the fog; but when the distance is considerable, the whitish colour becomes very perceptible; to such a degree that it is impossible to see through it. The water of the sea appears green at a certain depth; but when you take up a small quantity, as much, for instance, as a glass will contain, it is sufficiently diaphanous, and has no sensible colour: but in a great extent, when you look towards the bottom, so many greenish rays collected produce a deep colour.

27th July, 1760.

LETTER XXXIII.

Of Rays issuing from a distant luminous Point, and of the Visual Angle.

As long as the rays produced by the rapid vibration of the minuter particles of a body move in the same transparent medium, they preserve the same direction, or diffuse themselves in all directions, in straight lines. These rays may be represented by the radii of a circle, or rather of a sphere, which, issuing from a centre, proceed in straight lines to the circumference; and it is on account of this resemblance that we employ the same term *radius*, or ray, to express them, though, properly speaking, the light does not consist of lines, but of very rapid vibrations, going continually forward, in the direction of straight lines; and, for this reason, light

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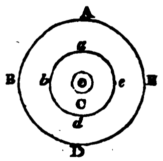
Switzerland, and the fine blue colour of the Rhone, in issuing out of the Lake of Geneva.—*Ed.*

The colour of the water, beautifully transparent as it issues with great velocity from the lake, is more green than blue.—*Am. Ed.*

may be considered as straight lines, issuing from a luminous point, in all directions.*

Fig. 11.



Let C, *Fig.* 11, be a luminous point, from which rays issue in all directions. Let two spheres be described round C, as a centre, of the one of which, let the great circle be *a b d e*, and of the other A B D E. The light diffused over the surface of the smaller sphere *a b d e* will likewise occupy that of the greater sphere A B D E. The light, then, must be more faint and weak at the surface of this last than at that of the smaller sphere *a b d e*. Hence it may be concluded, that the effect of light must be smaller in proportion to the distance from the luminous point. If we suppose that the radius of the greater sphere is double that of the smaller, the surface of the greater sphere will be four times as great. Since, therefore, the same quantity of light is diffused over the surface of the greater sphere, and over that of the smaller, it must follow that light at double the distance is four times more faint; at thrice the distance, nine times; at a quadruple distance, sixteen times; and so on.

On applying this rule to the light of the sun, it will appear, that if the earth were removed to double the distance from the sun, the light derived from him would be rendered four times more faint; and if the sun were a hundred times farther from us, his brightness would be a hundred times a hundred, that is, ten thousand times less. Supposing, then, a fixed star to be as great and as luminous as the sun, but that it was 400,000 times farther from us, its light will be 400,000 times 400,000, that is, 160,000,000,000 times more faint than that of the sun. Hence we see, that the light of a fixed star is nothing compared to that of the sun; and this is the reason that we do not see the stars in the daytime; as a feebler light always disappears in presence of one much more bright. The same thing holds good with respect to candles, and all other luminous bodies which administer less light in proportion to their distance from us; and you must have frequently remarked, that however strong a light may be, it is insufficient to assist us in reading a printed book, if you remove from it to any considerable distance.

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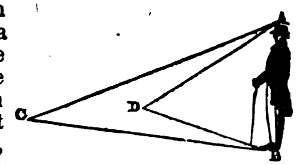
* It is difficult to conceive why a ray of light should be confined in its direction to straight lines, if it consist only in the vibrations of an elastic and universally-pervading ether. There is nothing in sound analogous to this. A luminous body, as a star or a candle, cannot be seen through a crooked tube. Sound, or mere undulations of an elastic medium, yield to no such obstruction. *Newton* was of opinion, that ethereal pulsation produced by the sun would circumvolve the earth, and that on this theory there should be no darkness at all.—*Am. Ed.*

There is still another circumstance closely connected with what I have just observed, namely, that the same object appears smaller to us in proportion to its distance. A giant at a great distance does not appear taller than a dwarf near us. To form a clearer judgment of this, it is necessary to attend to the angles at which these objects are seen by us.

Fig. 12.



Let us suppose, then, A B, *Fig.* 12, to be an object, for example, a man, and that the eye looks at it from the point C. Draw from that point the straight lines A C and B C, which represent the extreme rays proceeding from the object to the eye; we call the angle formed at C the visual angle of that object for the point C. If we look at the same object from a smaller distance, at D, the visual angle D will be undoubtedly greater: hence it is clear, that the more distant the same object is, the smaller is its visual angle; and the nearer it approaches, its visual angle becomes greater.

Astronomers measure very accurately the angles under which we see the heavenly bodies; and they have found that the visual angle of the sun is somewhat more than half a degree. If the sun were twice as far from us, this angle would be reduced to the half; and then it will not seem surprising that it should furnish us four times less light. And if the sun were 400 times farther off, his visual angle would become so many miles less, and then that luminary would appear no greater than a star. We must therefore carefully distinguish the apparent greatness of any object from its real greatness. The first is always an angle greater or less, according as the object is nearer or more distant. Thus the apparent greatness of the sun is an angle of about half a degree, whereas his real magnitude far surpasses that of the earth; for the sun being a globe, his diameter is estimated to be about 790,000 English miles, while the diameter of the earth is only 7912 English miles.

29th July, 1760.

LETTER XXXIV.

Of the Assistance which Judgment lends to Vision.

What I have now submitted to you on the phenomenon of vision belongs to optics, which is a branch of mixed mathematics, and which likewise holds a considerable rank in physics. Besides colours, the nature of which I have endeavoured to explain, it is the business of optics to treat of the manner in which vision is performed, and of the different angles under which objects are seen.

You must have already remarked, that the same object may be viewed, sometimes under a greater visual angle, sometimes under a smaller, as it is less or more distant from us. I say, further, that a small object may be viewed under the same angle as a great one, when the former is very near, and the latter very distant. A small dish may be placed before the eye in such a manner as to cover the whole body of the sun; and, in reality, a plate of half a foot diameter, at the distance of 54 feet, exactly covers the sun, and is seen under the same angle; and yet what a prodigious difference is there between the size of a plate and that of the sun. The full moon appears to us under nearly the same visual angle as the sun, and of consequence, nearly as great, though really much smaller; but it is to be considered that the sun is almost 400 times more remote from us than the moon.

The visual angle is a point of so much the more importance in optics, that the images of the objects which paint themselves on the bottom of the eye depend upon it. The greater or less the visual angle is, the greater or less they (the objects) are great or little. And as we see objects out of ourselves only so far as their images are painted on the bottom of the eye, they constitute the immediate object of vision or sensation. One of these images, therefore, leads us to the knowledge only of three things. First, its figure and its colours conduct to the conclusion, that there is, out of us, a similar object of such a figure, and such a colour. Secondly, its magnitude discovers the visual angle under which the object appears to us; and, finally, its place on the bottom of the eye makes us sensible of the direction of the external object relatively to us, or that in which the rays emitted from it reach our eyes.

In these three particulars consists the phenomenon of vision; and we only perceive, 1st, the figure and colours; 2dly, the visual angle, or the apparent magnitude; and, 3dly, the direction, or the place in which we conclude that the object exists. Vision, then, discovers to us nothing respecting either the real magnitude of objects, or their distances. Though we frequently imagine that we can determine by the eye the magnitude and distance of an object, this is not an act of vision, but of the understanding. The other senses, and habits of long standing, enable us to calculate at what distance an object is from us. But this faculty extends only to objects at no great distance. Whenever their distance becomes considerable, our judgment cannot exercise itself with certainty; and if sometimes we venture to hazard a decision, it is generally very remote from the truth.

Thus, no one can pretend to say that he sees the magnitude or the distance of the moon; and when the vulgar imagine they can judge of the first, by considering it as equal to that of the terrestrial bodies which are seen under the same angle, it is not by vision they are deceived, but by their judgment, which they want to apply to an object far beyond their reach. It is certain, therefore, that the eyes alone can determine nothing respecting the distance and magnitude of objects.

To this subject may be referred the very remarkable case of a man born blind, who obtained sight by means of an operation, at an advanced period of life.* This person was at first dazzled; he could distinguish nothing as to the magnitude and distance of objects. All objects appeared so near that he wanted to handle them. A considerable time and long practice were requisite to bring him to the real use of sight. He was under the necessity of serving a long apprenticeship, such as we perform during the term of childhood, and of which we afterward prèserve no recollection.

This it is which instructed us, that an object appears to us so much the more clear and distinct as it is nearer; and reciprocally, that an object which appears clear and distinct is near; and when it appears obscure and indistinct, that it is at a distance. It is thus that painters, by weakening the tints of the objects which they wish to appear remote, and strengthening those which they would represent as nearer, are enabled to determine our judgment conformably to the effect which they mean to produce. And they succeed so perfectly, that we consider some of the objects represented in painting as more distant than others, an illusion which could not take place if vision discovered to us the real distance and magnitude of objects.

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* This was the young man, blind from cataract, on whom our countryman *Cheselden* performed the operation of couching. An account of this interesting case, which is so often referred to, will be found in the *Philosophical Transactions* for 1728, vol. xxxv. p. 447.—*Ed.*

1st August, 1760.

LETTER XXXV.

Explanation of certain Phenomena relative to Optics.

You have just seen, that vision alone discovers to us nothing respecting either the real magnitude or the distance of objects; and that all we imagine we see, whether as to the distance or magnitude of any object, is the effect of judgment. We must carefully distinguish that which the senses represent to us, from what judgment adds, in which we frequently deceive ourselves. Many philosophers who have declaimed against the accuracy of the senses, and who meant thence to infer the uncertainty of all human knowledge, have confounded the proper representation of our senses with judgment.

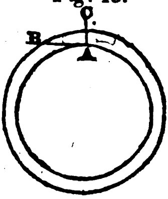
This is their mode of reasoning: We see the sun no bigger than a trencher, though it be infinitely greater; therefore the sense of seeing deceives us; therefore all our senses deceive us; at least, we cannot depend on them; therefore, all the knowledge we acquire by means of the senses is uncertain, and probably false: we therefore know nothing. Such is the reasoning of these skeptics, who boast so vaingloriously of their ingenuity; though there be nothing so easy as to say that every thing is uncertain; and the greatest dunce may make a shining figure in this sublime philosophy. But it is absolutely false that the sight represents to us the sun no bigger than a pewter plate; it determines nothing whatever respecting his magnitude; it is our judgment alone that deceives us. When the objects, however, are not very distant, we can pronounce with tolerable exactness on their dimensions and distances; and the other senses, joined to the degree of clearness with which we see these same objects, render our judgments sufficiently certain. Now, as soon as we have the idea of the distance of an object, we form to ourselves, likewise, that of its real magnitude, knowing that it depends on that distance. Hence, the more distant we reckon an object to be, the greater we conclude is its magnitude: and reciprocally, the nearer we conclude it is, the smaller we suppose it. We, of course, frequently take one body for another of much greater magnitude, when a suspension of judgment prevents our taking distance into the account. The reason is, that a very large body may be seen at a great distance, under the same angle as a small object placed near us.

There is another phenomenon well known to every one, and which has given occasion to many disputes among the learned, and which it is now perfectly easy to explain. The full moon appears to every eye at the time of her rising to be much greater than when she has got to a considerable height above the horizon, though the visual angle of the apparent magnitude be the same. The sun, too, at the time of rising and setting, appears to every one greater than at noon. What then is the foundation of this judgment, so universal, and so false? It is undoubtedly because we judge the sun and the moon in the horizon to be at a greater distance from us than when they have got to a considerable height.

But how come we to form such a judgment? The common answer is, that when the sun and the moon are in the horizon, we perceive a great many objects between them and us which seem to increase their distance; whereas, when the sun and moon have risen to a great height, we perceive nothing between them and us, and therefore conclude that they are nearer. I know not whether this explanation will be satisfactory. It may be objected, that an empty apartment appears greater than one completely furnished, though the size be exactly the same; several intervening objects, therefore, do not always lead us to imagine that one more remote is at a greater distance than is really the case. I flatter myself that the following solution will be deemed more natural and better founded.

Let the circle A, *Fig.* 13, represent the earth, and the dotted circle the atmosphere or air with which the earth is surrounded; suppose yourself stationed at the point A, if the moon is in the horizon, the rays will reach you in the direction of the line B A; but in her extreme height, the rays will descend in the line C A. In the first case the rays pass through the greater space B A, and in the second case through the smaller space C A. Now you will please to recollect, that the rays of light which pass through a transparent medium have their force diminished in proportion to the length of the passage. The atmosphere or air, then, being a transparent medium, the ray B A must in its passage lose much more of its force than the ray C A. Hence it follows in general, that all the celestial bodies appear much less brilliant in the horizon

Fig. 13.



than when fully risen and elevated. We are able to look directly even at the sun when he is in the horizon; but when once he has gained a certain height, the eye is constrained to shrink from his lustre.

I conclude from this that the moon, too, appears less brilliant in the horizon than when elevated.[*] Now you will recollect what I said a little above, in speaking of effect in painting, that the same object appears to us more distant when its light is weakened: the moon, then, being in the horizon, must appear more distant than at any point of elevation. The consequence is obvious; as we judge the distance of the moon greater in the horizon, we must likewise judge her magnitude greater. And in general all the stars, when near the horizon, appear to us greater, because their apparent distance is greater.

3d August, 1760.

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[*] A more complete explanation of this phenomenon will be found in Dr. Smith's *Optics*, vol. i. p. 63. He shows that the apparent figure of the sky resembles B F E D, *Fig*. 32, p. 183, being much less than a hemisphere; and considering that the moon at *m n* subtends an angle *m* O *n* equal to the angle *o* O *p*, which it subtends at *o p*, he concludes that the moon must appear much larger at *o p* than at *m n*, in consequence of its being supposed to be at a much greater distance. When a star seemed to be half-way between the horizon and the zenith, Dr. Smith found its real altitude to be only 23°; and upon this principle he constructed the following table:—

Sun or Moon's altitude, in degrees.	Apparent diameters, or distances.
0	100
15	68
30	50
45	40
60	34
75	31
90	30.—*Ed*.

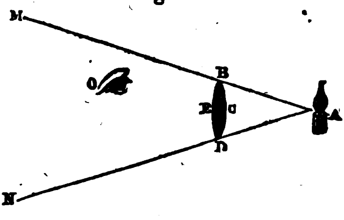
LETTER XXXVI.

Of Shadow.

I HAVE endeavoured to explain almost all that is usually treated of in optics. All that remains is to speak of shadow. You already know too well what is meant by *shade* or *shadow*, to render it necessary for me to dwell long on the subject. Shadow always supposes two things: a luminous body, and an opaque body which does not transmit the rays of light. The opaque body, then, prevents the rays of a luminous body from getting behind it, and the space which the rays cannot reach from this interception is called the shadow of the opaque body; or, what comes to the same thing, shadow includes all that space in which the luminous body is not to be seen, because the opaque body obstructs its rays.

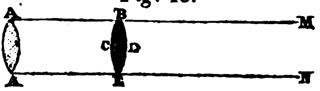
Let A, *Fig.* 14, be a luminous point, and B C D E an opaque body. Draw the extreme rays A B M, A D N, touching the opaque body. It is evident that no ray of light proceeding from A can penetrate into the space M B E D N; and in whatever point within that space the eye may be placed, at O, for example, it will not see the luminous body. This space is the shadow of the opaque body; and we see that it is continually increasing, and may extend to infinity. But if the body from which the rays proceed be itself of great magnitude, the determination of the shadow

Fig. 14.



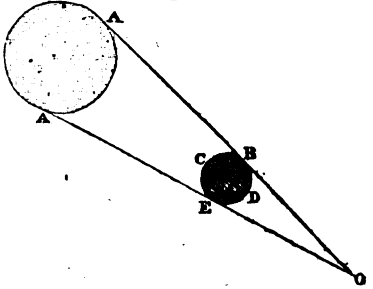
is somewhat different. There are three cases which demand consideration; the first is, when the luminous body is less than the opaque; the second, when they are equal; and the third, when the luminous body is the greater. The first case is that which we have now been considering, in which the light is smaller than the opaque body.

Fig. 15.



The second is represented in *Fig.* 15, where the luminous body A is of the same magnitude with the opaque body B C E D. If you draw the extreme rays A B M, A E N, the space M B E N will be shaded, and through the whole of that space it will be impossible to see the luminous body. You see likewise that the lines B M and E N are parallel, and that the shadow extends to infinity, always preserving the same breadth.

Fig. 16.



The third case is exhibited in *Fig.* 16, where the luminous body A A is greater than the opaque body B C E D. The extreme rays touching the opaque body in B and E, if produced, will meet in the point O, and the space of the shadow B O E becomes finite, and terminates in O. The shade in this case is termed conical. It is only into this space that the light has

no admission, and in which it is impossible to see the luminous body. To this third case belongs the shadows of the celestial bodies, which are much smaller than the luminous body which enlightens them, namely, the sun.

We have here, then, another display of the Creator's wisdom. For if the sun were smaller than the planets, their shadows would not be terminated, but extend to infinity, which would deprive immense spaces of the benefit of the sun's light. But the magnitude of that luminary surpassing by so many times that of the planets, their shadows are contracted to very narrow bounds, from which alone the light of the sun is excluded.

It is thus that the earth and the moon project their conical shadows; and the moon may occasionally plunge into the shadow of the earth either partially or totally. When this takes place, we say the moon is eclipsed, either wholly or in part. In the former case we call it a total eclipse of the moon; in the other, a partial eclipse. The moon likewise projects her shadow, but it is smaller than that of the earth. It may happen, however, that the shadow of the moon should extend as far as to the earth; and then those who are involved in that shadow undergo an eclipse of the sun. An eclipse of the sun, then, takes place when the moon, interposing, prevents our seeing the sun wholly, or in part. We see not the sun by night, though there be no eclipse; but we are then in the shadow, of the earth, which causes our greatest obscurity.

Hitherto we have considered only the cases in which the rays of light are transmitted in straight lines, which is the professed object of optics. But it has been already remarked, that the rays of light are sometimes reflected, and sometimes broken or refracted. You will recollect, that when the rays fall on a well-polished surface, such as a mirror, they are reflected from that surface; and when they pass from one transparent medium to another, they undergo refraction, and are in some sense broken. Hence arise two other sciences. That which considers vision in reference to reflected rays is called *catoptrics;* and that which has for its object vision, in reference to broken or refracted rays, is termed *dioptrics.* Optics treat of vision relatively to direct rays of light. I shall present you with a summary of these two sciences catoptrics and dioptrics, as they disclose phenomena which are every day presenting themselves, and of which it is of importance to investigate the causes and the properties. Every thing relating to the subject of vision is, beyond contradiction, an object highly worthy of exciting curiosity, and of engaging attention.

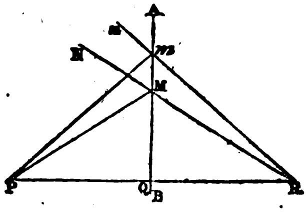
5th August, 1760.

LETTER XXXVII.

Of Catoptrics, and the Reflection of Rays from plain Mirrors.

Catoptrics treat of vision relatively to reflected rays. When rays of light fall on a well-polished surface, they are reflected in such a manner that the angles on all sides are equal among themselves.

Fig. 17.



To set this in a clear light, let A B, *Fig.* 17, be the surface of a common mirror, and P a luminous point, whose rays P Q, P M, P *m*, fall upon the mirror. Of all these rays, let P Q be that which falls perpendicularly on the mirror, and which has this particular and remarkable property, that it is reflected upon itself in the direction of Q P; just as on a billiard-table, when the ball is struck perpendicularly against the ledge, it is repelled in the self-same direction. But every other ray, as P M, is reflected in the line M N, in such a manner as to make the angle A M N equal to the angle B M P; in which it is to be remarked, that the ray P M is named the incident ray, and M N the reflected ray. In like manner, to the incident ray P *m* will correspond the reflected ray *m n*; and, consequently, because of the reflection, the ray P M is continued in the direction of the line M N, and the ray P *m* in the direction of *m n*, so that we have the angle A M N equal to B M P, and the angle A *m n* equal to the angle B *m* P. This property is thus enounced: *The angle of reflection is always equal to the angle of incidence.*

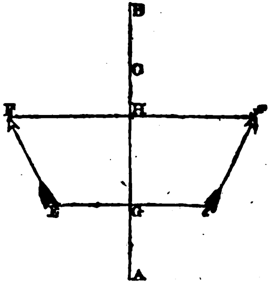
I have already taken notice of this striking property; but my design at present is to show what the phenomena in vision are which result from it. First, it is evident that an eye placed at N will receive from the luminous point P the reflected ray M N; thus the ray which excites in that eye the sensation of the body from whence it proceeded comes in the direction M N, just as if the object P were in some point of that line; hence it follows that the eye must see the object P in the direction N M.

In order the more clearly to elucidate this fact, we must have recourse to geometry; and you will recollect with pleasure the propositions on which the following reasoning is founded. Let the perpendicular ray P Q be produced on the other side the mirror to R, so that Q R shall be equal to P Q; I will show you that all the reflected rays M N and *m n*, being produced behind the mirror, must meet in that point. For, taking the two triangles P Q M and R Q M, they have first the side M Q common to both; then the side Q R was made equal to the side P Q; and, finally, the angle P Q M being a right angle, its adjacent angle R Q M must likewise be a right angle (Euclid's Elements, Book I. Prop. 13). Therefore these two triangles, having each an equal angle contained by two equal sides, shall be every way equal (Euclid, Book I. Prop. 4); and consequently the angle P M Q equal to the angle R M Q. But the angle A M N, and the angle R M Q, being vertical, are equal to each other (Euclid, Book I. Prop. 15); therefore also the angle A M N shall be equal to the angle P M Q; that is, the angle of reflection shall be equal to the angle of incidence.

In the same manner it is demonstrated, that the reflected ray *m n*, being produced, would likewise pass through the point R, and consequently produce in the eye the same effect as if the object P were actually placed behind the mirror at R, this point being in the perpendicular P Q R, at the same distance as P from the surface of the mirror, but on different sides. This will enable you to comprehend clearly why mirrors represent objects as if they were behind them; and why we judge that these objects are placed as far behind the surface of the mirror as they really are before it. It is thus that the mirror transports objects into another place, without changing their appearance. To distinguish in the mirror the apparent object from the real, we name the apparent object the image, and we say that the images represented by reflected rays are behind the mirror. This denomination serves to distinguish real objects from the images of them represented in mirrors; and the images which we see in mirrors are perfectly equal and similar to the objects, with this exception, that what in the object is on the left appears in the image on the right, and reciprocally. Thus a person wearing his sword on the left side, appears with it in the mirror on his right.

From what has been said, it is always easy to settle the image of any object whatever behind the mirror.

Fig. 18.



For A B, *Fig.* 18, being a mirror, and E F an object, say an arrow: draw from the points E and F the perpendiculars E G and F H, to the surface of the mirror, and produce these to *e* and *f*, so that E G shall be equal to *e* G, and F H to *f* H, *e f* will be the image sought, which will be equal to the object E F, because the quadrilateral figure G *e f* H is in all respects equal to the quadrilateral figure G E F H. It must be still farther remarked, that were you even to cut off from the mirror a part, as C B, and A C was the mirror, the image *e f* would not be changed. And consequently, when the mirror is not sufficiently large to admit the falling of the perpendiculars E G and F H upon it, we must suppose the plane of the mirror to be extended, as we produce lines in geometry when we want to let fall perpendiculars upon them. What I have said respects only common mirrors, whose surface is perfectly plain. Convex and concave mirrors produce different effects.

7th August, 1760.

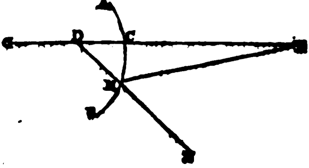
LETTER XXXVIII.

Reflection of Rays from Convex and Concave Mirrors. Burning Mirrors.

Every thing relating to the reflection of rays is reduced, as you have seen, to two things; the one of which is the place of the image which the reflected rays represent; and the other the relation of the image to the object. In ordinary or plain mirrors, the image of the object is behind the mirror, at a distance equal to that of the object before the mirror, and it is equal and similar to the object. To both of these circumstances we must attend when the mirror is not plain, but when its surface is convex or concave; for in either case the image is, for the most part, strangely disfigured. You must frequently have remarked that on presenting any object before a spoon very highly polished, you see its image greatly disfigured, whether reflected from its interior surface, which is concave, or from its exterior, which is convex.

A globe of silver, finely polished, represents objects with sufficient accuracy, but in miniature. If the interior surface of the globe is well polished, objects appear upon it magnified; provided always that they are not too distant. For the same objects may likewise appear smaller and inverted, if they are removed far from the mirror. There is no occasion to take a whole globe; any part of its surface whatever produces the same effect. These mirrors are denominated spherical; and there are two sorts of them. The one is convex and the other concave, according as they are taken on the exterior or interior surface of the sphere. They are compounded of various metals, susceptible of a fine polish; whereas plain mirrors are made of a plate of glass, and covered on one side with a preparation of mercury, designed to stop the passage of the rays, and to reflect them. I begin with convex mirrors.

Fig. 19.

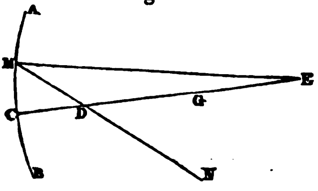


Let A C B, *Fig.* 19, be a mirror, the segment of a sphere, whose centre is G. If you place before this mirror an object E, at a great distance, its image will appear behind

the mirror, at the point D, the middle point of the radius of the sphere C G; and the magnitude of this image will be to that of the object in the relation of the lines C D and C E: it will therefore be in this case much smaller than the object, as the line C D is in effect much smaller than the line C E. If the object E approaches to the mirror, so likewise will its image. This is all demonstrable on geometrical principles, by supposing that any incident ray whatever, say E M, is reflected in the direction of M N, so that the angle B M N may be equal to the angle C M E. Thus, when the eye is at N, receiving the reflected ray M N, it will see the object E, according to that direction, and will observe it in the mirror at the point D; or, in other words, D will be the image of the object placed at E, but smaller. It is likewise easy to see, that the smaller the sphere is, of which the mirror is a segment, the more likewise is the image diminished.

I proceed to concave mirrors, the use of which is very common on many occasions. Let A C B, *Fig*. 20, be a mirror, forming part of a sphere, whose centre is G, and G C a radius. Let us suppose an object E very distant from the mirror, its image will appear before the mirror at D, the middle point of the radius C G; for any ray of light whatever, E M, from the object E, falling on the surface of the mirror at the point M, will be reflected thence in such a manner as to pass through the point D; and when the eye is placed at N, it will see the object at D; but this image will be to the object in the ratio of C D to C E, and consequently in this case smaller than it. And when you

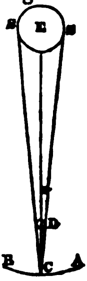
Fig. 20



bring the object nearer to the mirror, the image retires; the object being placed even at the centre G, the image is there likewise. If you bring the object still forward to D, the image will retire infinitely beyond E. But if the object be placed still farther forward, between C and D, the image will fall behind the mirror, and appear greater than the object.

When you look at yourself in such a mirror, at some point between D and C, your face will appear frightfully large. This is explained by the nature of reflection, in virtue of which the angle of incidence E M A is always equal to the angle of reflection C M N. To this species must be referred burning mirrors, and every concave mirror may be employed to burn. This remarkable property merits a more particular explanation.

Fig. 21.



Let A B C, *Fig.* 21, be a concave mirror, whose centre is G, and instead of the object, let the sun be at E; his reflected rays will represent the image of the sun at D, the middle point between C and G. Now, the magnitude of this image will be determined by the extreme rays S C, S C. This image of the sun will be accordingly very small; and as all the rays of the sun which fall on the mirror A B C are reflected in this image, they will be collected there, and will have so much more force, as the image D is smaller than the surface of the mirror. But the rays of the sun are endowed with the property of heating the bodies on which they fall, as well as that of illuminating them; hence it follows that there must be at D a great degree of heat; and when the mirror is sufficiently large, this heat may become stronger than the most ardent fire. In fact, by means of such a mirror you may burn in an instant any combustible body, and even melt metals of every kind. It is the image of the sun alone which produces these surprising effects.* This image is usually denominated the focus of the mirror; it falls always in the middle point of the radius C G, between the mirror and its centre G.

You must carefully distinguish *burning mirrors* from *burning-glasses*, of which I shall give some account in my next Letter.

9th August, 1760.

LETTER XXXIX.

Of Dioptrics.

Having explained the principal phenomena of *catoptrics*, which result from the reflection of the rays of light, I proceed to treat of *dioptrics*, whose object is to unfold the phenomena of the refraction of rays, which takes place when they pass through different transparent mediums. A ray of light does not pursue the same straight line, unless it continues its progress through the same medium. As soon as it enters another transparent medium, it changes its direction more or less, according as it falls upon it more or less obliquely. There is only one case in which it pursues a rectilinear course, namely, when it enters the other medium perpendicularly.

The instruments principally to be considered in dioptrics are the glasses employed in the construction of telescopes and microscopes. These glasses are of a circular form, but with two faces. Every thing relating to them is reducible to the figure of these two faces, which may be plain, or convex, or concave. Their convexity or concavity is always equal to that of a sphere, of which the radius must be known, it being considered as the measure of the curve of those surfaces. This being laid down, we shall have several kinds of dioptric glasses.

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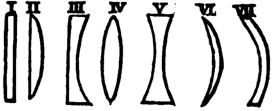
* The author could hardly mean that a mere image could produce such an effect as is here spoken of. If light or heat consists of ethereal pulsations, there must be a concentration of the vibratory pulses in the focus of the mirror, as aerial pulses are brought to a point in a whispering-gallery, or in the axis of an ear-trumpet.—*Am. Ed.*

Fig. 22.

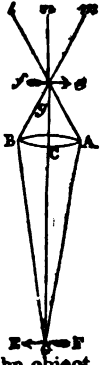


The first species, No. I. *Fig.* 22, is that whose two faces are plain. By cutting a circular piece out of a plate of glass of equal thickness, we shall have one of this species which makes no change on objects either as to magnitude or distance. Glass No. II. has one of its surfaces plain, and the other convex; and such are termed *plano-convex*. The third species, No. III., has one face plain, and the other concave; and these are called *plano-concave*. The fourth, No. IV., has two convex surfaces; and is called *double-convex*. No. V. has two concave surfaces, and is called *double-concave*. The species Nos. VI. VII. have one surface convex and the other concave; and we give them the name of *meniscus*. All these lenses are reducible to two classes; the one containing those in which convexity prevails, as Nos. II., IV., VI.; in the other, concavity is predominant, namely, Nos. III., V., VII. The former class is simply denominated convex, and the latter concave. These two classes are distinguished by the following property.

Let A B, *Fig.* 23, be a convex glass, exposed to a very distant object E F, whose rays G A, G C, G B, fall on the glass, and passing through it, undergo a refraction which will take place in such a manner, that

the rays proceeding from the point G shall meet on the other side of the glass in the point *g*. The same thing will happen to the rays which proceed from every point of the object. By this alteration all the refracted rays A *l*, B *m*, C *n*, will pursue the same direction as if the object were at *e*, *g*, *f*, and inverted; and it will appear as many times smaller as the distance C *g* shall be contained in the distance C G. We say, then, that such a glass represents the object E F behind it at *e f*; and this representation is called the *image*, which is consequently inverted, and is, with the object itself, in the ratio of the distances of the glass from the image, and of the glass from the object.

Fig. 23.

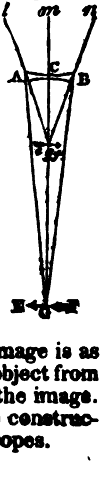


It is clear, then, that if the sun were the object, the image represented at *e f* would be that of the sun; though very small, it will be so brilliant as to dazzle the eye, for all the rays which pass through the glass meet in this image, and they exercise their double power of giving light and heat. The heat there is nearly as many times greater as the surface of the glass exceeds in magnitude the image of the sun, named its *focus*, from which, if the glass be very great, you may produce the greatest effects of heat. Combustible substances placed in the focus of such a glass are instantly consumed. Metals are melted, and even vitrified by it; and other effects are produced far beyond the reach of the most active and intense fire.

The reason is the same as in the case of burning mirrors. In both, the rays of the sun, diffused over the whole surface of the mirror or glass, are collected in the small space of the sun's image. The only difference is, that in mirrors the rays are collected by reflection, and in glasses by refraction. Such is the effect of convex glasses, which are thicker in the middle than at the extremities, and which I have represented in Nos. II., IV., and VI. Those represented in Nos. III., V., and VII. are thicker at the extremities than at the middle; and being all comprehended under the term concave, produce a contrary effect.

Let A C B, *Fig.* 24, be a glass of this form. If you expose to it, at a great distance, the object E G F, the rays G A, G C, G B, proceeding from the point G, will undergo a refraction, on leaving the glass in the direction of A *l*, C *m*, and B *n*, as if they had issued from the point *g*; and an eye placed behind the glass, at *m*, for example, will see the object just as if it were placed at *e g f*, and in a situation similar to that in which it is at the point G, but as many times smaller as the distance C G exceeds the distance G *g*. Convex glasses, then, represent the image of a very distant object behind them, concave glasses represent it before them; the former represent it inverted, and the latter in its real situation. In both the image is as many times smaller as the distance of the object from the glass exceeds that of the glass from the image. On this property of glasses is founded the construction of telescopes, spectacles, and microscopes.

Fig. 24.



11th August, 1760.

LETTER XL.

Continuation.—Of Burning-glasses and their Focus.

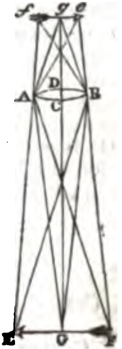
CONVEX glasses furnish some further remarks, which I beg leave to lay before you. I speak here of those glasses in general which are thicker in the

middle than at the extremities; whether both surfaces be convex, or one plain and the other convex; or, finally, one concave and the other convex; provided, however, that the convexity exceed the concavity, or that the thickness be greater at the middle than at the extremities. It is further supposed, that the glasses have a spherical figure.

They have first this property, that being exposed to the sun, they present behind them a focus, which is the image of that luminary, and which is endowed, like it, with the property of illuminating and burning. The reason is, that all the rays issuing from the sun, and falling on this surface, are collected by the refraction of the glass into a single point. The same thing happens, whatever be the object exposed to such a glass; it always presents the image of it, which you see instead of the object itself. The following figure will render what I have said more intelligible.

Let A B C D, *Fig.* 25, be a convex glass, before which is placed an object E G F, of which it will be sufficient to consider the three points E, G, F. The rays which, from the point E, fall upon the glass, are contained in the space A E B; and are all collected in the space A *e* B by refraction, so as to meet in the point *e*. In the same manner, the rays from the point G, which fall on the glass, and which fill the space A G B, are comprehended by means of refraction in the space A *g* B, and meet in the point *g*. Finally, the rays from the point F, which fall on the glass in the angle A F B, are refracted so as to meet in the point *f*. Thus we shall have the image *e g f* in an inverted position behind the glass; and an eye placed at O, behind the image,

Fig. 25.



will be affected in the same manner as if the object were at *e g f* inverted, and as many times smaller as the distance D *g* is smaller than the distance C G.

In order to determine the place of the image *e g f*, we must attend as well to the form of the glass as to the distance of the object. As to the first, it may be remarked, that the more convex the glass is, in other words, the more that the thickness of the middle C D exceeds that of the extremities, the nearer the image will be to its surface. With regard to the distance, if you bring the object E F nearer to the glass, its image *e f* retires from it, and reciprocally. The image cannot be nearer to the glass than when the object is at a very great distance from it. The image is then at the same distance as that of the sun would be, which point is denominated the focus of the lens. When the object, then, is very distant, the image falls in the very focus; and the nearer you bring the object to the glass, the farther the image retires from it, and that in conformity to a law in dioptrics, by means of which you can always determine the place of the image for every distance of the object, provided you know the focus of the glass, that is, the distance at which it collects the rays of the sun, in a space sufficiently small to set on fire a body exposed to it.

The point where the rays meet is, as has been said, the place of the image. Now, this point is easily found by experience. The different denominations of glasses are derived from it, as when we say, such a glass has its focus at the distance of an inch, another at the distance of a foot, another at the distance of ten feet, and so on; or, more concisely, a glass of an inch, a foot, or ten feet focus. Long telescopes require glasses of a very distant focus, and it is extremely difficult to make them exact. I once paid 150 crowns for one lens, which I sent to the academy of Petersburg; it has its focus at the distance of 600 feet.* I am convinced it was of no great value; but they wished to have it on account of its rarity.

To be satisfied that the representation of the image *e g f* in *Fig.* 25 is real, you have only to hold at that place a piece of white paper, the particles of which are susceptible of the different kinds of vibrations on which colours depend. Then all the rays from the point E of the object, on meeting at the point *e*, will put the particles of the paper into a movement of vibration similar to that which the point E has, and consequently you will see the point *e* of the same colour as the point E. In like manner the points *g* and *f* will have the same colours as the points G and F of the object; and you will likewise see on the paper all the points of the object expressed in their natural colours; which will represent the most exact and the most beautiful picture of the object. This will succeed perfectly well in a dark room, by applying a convex lens to a hole made in the shutter. You will then see on a sheet of white paper, placed opposite to the aperture in the shutter, all the external objects so exactly painted, that you may trace them with a pencil. Painters make use of such a machine for designing landscapes and other views.†

13*th August*, 1760.

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* The largest lenses ground by Campani, of Bologna, had a focal length of 100 and 136 feet. Huygens presented to the Royal Society two lenses, one of which was 120, and the other 123 feet in focal length.—*Ed.*

† The theory of light adopted and illustrated by Euler in the preceding Letters, was originally proposed by Huygens in his *Traité de la Lumière*, published in 1690. In this ingenious work he has shown how all the phenomena of refraction and reflection may be explained and calculated, by the hypothesis that light consists of undulations of an ethereal medium; and he considers it as supported by the phenomena of double refraction. Notwithstanding the attempts of Euler to revive this theory, it fell into total neglect, and was received in no part of Europe as a branch of sound physics.

About the year 1800, Dr. Thomas Young ventured to maintain it,

LETTER XLI.

Of Vision, and the Structure of the Eye.

I AM now enabled to explain the phenomena of vision, which is undoubtedly one of the greatest operations of nature that the human mind can contemplate. Though we are very far short of a perfect knowledge of the subject, the little we do know of it is more than sufficient to convince us of the power and wisdom of the Creator. We discover in the structure of the eye perfections which the most exalted genius could never have imagined.

I shall not detain you at present with an anatomical description of the eye. It is sufficient to re-

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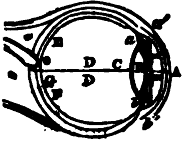
almost single-handed, against the rest of the philosophical world. He pointed out its applicability to explain a great variety of natural phenomena, that could not be referred to any general principle; and by his discovery of the law of interference, he may be said to have established the theory of undulations. The singular phenomena of the polarization and the double refraction of light, which were afterward discovered, have successively found an explanation in the theory of undulations; and some of the recent discoveries in that branch of optics may be considered as placing it upon the firmest basis.

The Newtonian doctrine, of the emanation of luminous particles, we have always regarded as the true one. A partiality for the name of its great founder, the simplicity with which it explains the general phenomena, and perhaps a portion of national feeling, have conspired to give it permanency in this country. The force of truth, however, compels us to acknowledge, that the theory of undulations is likely to be soon adopted by every philosopher who has studied the vast variety of phenomena which it embraces and explains. An account of the Huygenian theory of light will be found in the *Edinburgh Encyclopædia*, Art. Optica, vol. xv. p. 534.—*Ed.*

The theory of undulations appears evidently to have gained ground in the philosophical world since the foregoing note was written. It has been adopted, notwithstanding the authority of Newton and the greater simplicity of his hypothesis of emanations, by the most profound of the British philosophers; and on the Continent it is the prevailing theory. The most learned treatise on light recently published is that of Sir J. F. Herschel, in the *Encyclopedia Metropolitana*, in which this theory has received a strong support.—*Am. Ed.*

Fig. 26.



mark, that the exterior membrane *a* A *b*, *Fig*. 26, is transparent, and is called the *cornea* of the eye; behind this, on the inside, is another membrane *a'* *m*, *b'* *m*, circular and coloured, which we call the *iris*, in the middle of which is an aperture *m* *m*, called the *pupil*, which appears to us to be black. We find behind this aperture, the *crystalline humour*, *b* B C *a*, which is a body somewhat resembling in form a small burning-glass; it is perfectly transparent, and is covered with a thin membrane, called its *capsule*. Behind the crystalline humour the cavity of the eye is filled with a transparent jelly, called the *vitreous humour*. The anterior space between the thick coat *a* A *b* and the crystalline *a* *b* contains a fluid like water, which for that reason is called the *aqueous humour*.

Here, then, are four transparent substances, through which the rays of light that enter into the eye must pass: 1, the anterior coat, or *cornea*; 2, the *aqueous humour*, between A and B; 3, the *crystalline*, *b* B C *a*; 4, the *vitreous humour*. These four substances differ as to density; and the rays passing from one to another undergo a particular refraction; and they are so arranged, that the rays coming from a point of any object are still collected within the eye in a point, and there present an image.

The bottom of the eye at E G F, or the *retina*, is furnished with a whitish tissue, adapted to the reception of images: and it is thus, you will please to recollect, that the images of objects may be represented on a white ground. Conformably to the same principle, all the objects whose rays enter into the eye are found painted on the retina. Take the eye of an ox, and having removed the exterior parts which cover the retina, you will see all the objects painted there so exactly that no artist could surpass it, or even arrive at such a degree of perfection. And in order to see any object whatever, the object must always be painted on the retina; and when, unfortunately, any of the parts of the eye are injured, or lose their transparency, the person becomes blind.

But it is not sufficient, in order to our seeing objects, that their images should be painted on the retina; some are blind, though this takes place. Hence we see that images painted on the retina are not, after all, the immediate object of vision, and that the perception of the soul is communicated some other way. The retina is a reticulated contexture of nerves the most subtile, communicating with a great nerve, which, coming from the brain, enters the eye at O. and is denominated the *optic nerve*. These small nerves of the retina are agitated by the rays of light which form the image at the bottom of the eye; and this agitation is transmitted by the optic nerve to the brain. It is there, undoubtedly, that mental perception is formed; but the most dexterous anatomist is unable to pursue these nerves to their source—the union of the soul with the body must for ever remain a mystery.

15th August, 1760.

LETTER XLII.

Continuation. Wonders discoverable in the Structure of the Eye.

It will not be disagreeable to you, I hope, to contemplate with me, somewhat more attentively, the wonders discoverable in the structure of the eye.

And, first, the pupil presents an object highly worthy of admiration. It is that aperture which we find in the middle of the iris or star *m m*, by which the rays pass into the inside of the eye, and which appears black. The larger it is, the greater quantity of rays can enter into the eye, to form on the retina the image which appears painted there; thus the more the pupil is opened, the more brilliant this image will be.

On carefully examining the human eye, we observe that the aperture of the pupil is sometimes greater and sometimes smaller. It is generally remarked, that the pupil is contracted when exposed to a very strong light; and, on the contrary, very much dilated when the light is faint. This variation is absolutely necessary to the perfection of vision. When we are in a very strong light, the rays being more powerful, fewer of them are wanted to agitate the nerves of the retina; the pupil, accordingly, is then more contracted. Were it more dilated, and consequently admitted more rays, their force would agitate the nerves too violently, and occasion pain. It is for this reason we are unable to look upon the sun without being dazzled, and without experiencing a sensible pain in the bottom of the eye.

Were it possible for us to contract the pupil still more, so as to admit only a very small quantity of rays, we should not be very greatly incommoded by it; but the contraction of the pupil is not in our own power. Eagles possess this advantage, and are able to look directly at the sun; it is accordingly remarked, that their pupil is then so much contracted as to appear reduced to a point—a clear light requiring a very small dilatation of the pupil. In proportion as the light decreases, the pupil dilates, and in the dark it is so enlarged as almost to occupy the whole of the iris. If it remained in the same state of contraction as in the light, the rays which enter into it would be too weak to agitate the nerves as much as is necessary to vision; the rays must, therefore, be then admitted in greater abundance, in order to produce a sensible effect.

Were it in our power to open the pupil still more,* we should be able to see in a greater degree of darkness. To this purpose we are told of a person, who having received a blow on his eye, the pupil was so dilated by it that he could read and distinguish the minutest objects in the dark. Cats, and several other animals which roam in the dark, have the faculty of enlarging the pupil much more than the human species; and owls have theirs at all times too much dilated to bear even a moderate degree of light.

Now, when the pupil of the human eye dilates or contracts, it is not by an act of the will; man not having the power of dilating or contracting the pupil at pleasure. As soon as he enters into a luminous situation, it spontaneously contracts, and dilates on his return to darkness. But this change is not produced in an instant; it requires a little time for this organ to accommodate itself to circumstances.

You must, no doubt, have remarked, that as often as you make a very sudden transition from a clear light to a dark place, as in the theatre, you could not at first distinguish the company. The pupil was still too narrow to permit the few feeble rays which it admitted to make a sensible impression; but it gradually dilated to receive a sufficiency of rays. The contrary happens when you pass suddenly from darkness to a clear light. The pupil being then very much expanded, the retina is struck in a lively manner, you are quite dazzled, and under the necessity of shutting your eyes.

It is then a very remarkable circumstance, that the pupil should dilate and contract according as vision requires, and that this change should take place almost spontaneously and independently of any act of the will. Philosophers who examine the structure and the functions of the human body are greatly divided in opinion as to this subject; and there is little appearance that we shall ever have a satisfactory solution of this wonderful phenomenon.* The variability of the pupil is, however, an object essentially necessary to vision; and without which it would be very imperfect. But various other particulars are discoverable, equally entitled to admiration.

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* Although we cannot do this by muscular exertion, yet by putting a drop of the juice of the Belladonna, or of the Hyoscyamus, upon the eye, the pupil will dilate itself in an extraordinary degree, and retain itself in that state for *one or two* hours.—*Ed.*

17th August, 1760.

LETTER XLIII.

Further Continuation.—Astonishing Difference between the Eye of an Animal, and the Artificial Eye or Camera Obscura.

The principle on which the structure of the eye is founded is in general the same as that according to which I explained the representation of objects on white paper by means of a convex lens. Both of them must be resolved into this, that all the rays, proceeding from one point of the object, are again collected in a single point by refraction; and it seems of little importance whether this refraction is performed by a single lens or by the several transparent substances of which the eye is composed. It might even be inferred from thence, that a structure more simple than that of the eye, by employing one single transparent substance, would have been productive of the same advantages; which would amount to a very powerful objection against the wisdom of the

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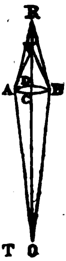
* The contraction and dilatation of the pupil are now generally ascribed by anatomists to the muscularity of the iris, stimulated more or less in proportion to the light which falls upon it.—*Am. Ed.*

Creator, who has assuredly pursued the simplest road in the formation of all his works.

Persons have not been wanting who, from not having attentively examined the advantages resulting from this apparent complication, presumed to censure this beautiful production of the Supreme Being with a levity worthy of censure. They have pretended it was in their power to produce a plan more simple for the structure of the eye, because they were ignorant of all the functions which that organ had to discharge. I shall examine this plan of theirs; and I hope to convince you that it would be highly defective, and altogether unworthy of being put in competition with that which actually exists.

Such an eye, therefore, would be reduced to a simple convex lens, A B C D, *Fig.* 27, which collects, in a point, all the rays coming from one and the same corresponding point in the object.

Fig. 27.



But this is only near to the truth. The spherical form given to the surfaces of a lens is liable to this inconvenience, that it does not completely collect in one and the same point the rays which pass through its centre and those which pass through its extremities. There is always a small difference, though almost imperceptible, in the experiments, by means of which we receive the image on a piece of white paper; but if this happened in the eye itself, it would render vision very confused.

The persons to whom I have been alluding allege, that it may be possible to find another figure for the surfaces of the lens, which shall have the property of collecting anew all the rays issuing from the point O, in a point R, whether they pass through the centre or through the extremities. I admit that this may be possible; but supposing the lens to pos-

sess this property with respect to the point O, at the fixed distance C O, it would not possess it at points at a greater or less distance from the lens; or even admitting this to be possible, which it is not, the lens would most certainly lose that property with regard to objects placed on one side, at T, for instance. Accordingly we see, when objects are represented on white paper, that though such as are directly before the lens, as at O, may be sufficiently well expressed, yet those which are obliquely situated, as at T, are always much disfigured, and very confusedly represented: and this is a defect which the most ingenious artist is incapable of rectifying.

But there is another, and one not less considerable. In speaking of rays of different colours, I remarked, that in passing from one transparent medium to another, they undergo a different refraction; that rays of a red colour undergo the least refraction, and violet-coloured rays the greatest. Hence, if the point O were red, and if its rays, in passing through the lens A B, were collected at the point R, this would be the place of the red image. But if the point O were violet, the rays would be collected nearer to the lens, at V. Again, as white is an assemblage of all the simple colours, a white object placed at O would form several images at once, situated at different distances from the point O; the result of which would be, on the retina, a coloured spot that would greatly disturb the representation.

It is accordingly observable, that when in a dark room the external objects are represented on white paper, they appear bordered with the colours of the rainbow; and it is impossible to remedy this defect by employing only one transparent body. But it has been remarked, that this may be done by means of different transparent substances; but neither theory nor practice have hitherto been carried to the degree of perfection necessary to the execution of a structure which should remedy all these defects.

But the eye which the Creator has formed is subject to no one of all the imperfections under which the imaginary construction of the freethinker labours. In this we discover the true reason why Infinite Wisdom has employed several transparent substances in the formation of the eye; it is thereby secured against all the defects which characterize every work of man. What a noble subject of contemplation! How pertinent that question of the Psalmist! *He who formed the eye, shall he not see? and He who planted the ear, shall He not hear?* The eye alone being a masterpiece that far transcends the human understanding, what an exalted idea must we form of Him who has bestowed this wonderful gift, and that in the highest perfection, not on man only, but on the brute creation, nay, on the vilest of insects!

19th August, 1760.

LETTER XLIV.

Perfections discoverable in the Structure of the Eye.

The eye, then, infinitely surpasses every piece of mechanism which human skill is capable of producing. The different transparent substances of which it is composed have not only a degree of density capable of causing different refractions, but their figure is likewise determined in such a manner, that all the rays proceeding from one point of the object are really collected in one and the same point, whether that object be more or less distant, whether it be situated directly or obliquely with respect to the eye, and though its rays undergo different refractions.

Were the least change to be made in the nature and figure of these substances, the eye would lose all the advantages which we have been admiring. The strength of our sight is exactly proportioned to the extent of our necessities; and far from complaining that objects too remote escape this organ, we ought, on the contrary, to consider it as one of the most precious gifts of the Supreme Being.

It must be further remarked, that in order to see objects distinctly, it is not sufficient that the rays which come from one point should be collected in another. It is likewise necessary that the point of reunion should fall precisely on the retina; if it fell either short of or beyond it vision would become confused. Now, if for a certain distance of objects this point of union fall upon the retina, those of more distant objects would fall on a part within the eye short of the retina; and those of nearer objects would fall beyond the eye. In either case there would be a confusion in the image painted on the retina.

The eyes of every man, therefore, are constructed for a certain distance. Some persons see distinctly only such objects as are very near to their eyes; we call them *Myops*, that is, short-sighted. Others, on the contrary, named *Presbytes*, see distinctly objects only which are very distant. And those who see distinctly objects at a moderate distance are said to have good eyes. Both the other two, however, have the power of contracting or dilating the globe of the eye to a certain degree, and thereby of bringing nearer, or of removing, the retina, which enables them likewise to see clearly objects a little more or less distant; this, undoubtedly, greatly contributes to render the eye more perfect, and it cannot surely be ascribed to chance merely.

Those who have good eyes derive most advantage from their structure, as they are thus in a condition to see distinctly objects very distant and very near; but this never exceeds a certain limit. There is, perhaps, no one who can see distinctly at the distance of an inch, and, consequently, still less at a

smaller distance. If you hold a piece of writing close to your eyes, you will see the characters but very confusedly. This is all I presume to offer on a subject of such high importance.*

21*st Aug*. 1760.

LETTER XLV.

Of Gravity, considered as a general Property of Body.

Having now treated of light,† I proceed to the consideration of a property common to all bodies—that of gravity. We find that all bodies, solid and fluid, fall downward when they are not supported.

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* The wonders of the human eye, so well pointed out by Euler, are still greater than he conceived He was not acquainted with the fact that the *crystalline lens* diminishes in density from the centre to the circumference, that it is composed of successive concentric laminæ, and that each of those laminæ consists of minute transparent fibres, varying in thickness, and arranged with the most beautiful symmetry in relation to the axis of vision. In some of the lower animals the structure of the crystalline lens is more perfectly displayed than in man, and exhibits most striking phenomena, both in reference to the variations in its density and the distribution of its fibres. The complication of its parts in some animals, and the admirable skill with which they are suited to the various purposes of their existence, exceed all description, and confound all human intelligence.—*Ed.*

† The subject of optics is resumed by our author in the 2d vol.—*Ed.*

It is not a difficult thing to study the structure of the eye, by taking out the eye of an animal recently killed, e. g. a sheep or a bullock, placing it on a saucer, and dissecting it carefully with a sharp knife. The beautiful figure and perfect transparency of the crystalline lens (which may be safely handled), the green lining of the choroid coat seen through the vitreous humour, the delicate expansion of the retina, the diffusion and ramification of the blood-vessels, the iris, the pupil, the cornea, and posteriorly the optic nerve, which connects the operations of this wonderful piece of Divine mechanism with the brain or sensorium, all become more impressive, and render the eye, as Dr. *Paley* observes, sufficient of itself to confound the skeptic.

It is remarkable that a person may by a little management see the blood-vessels of his own eye finely displayed, as it were, on a screen before him.

Let a lamp or candle be held in one hand, and keeping the eye steadily directed forward, move the light up and down, or sideways, on one side of the line of vision; an image of the blood-vessels will in a short time present itself, like the picture of a tree or shrub with its trunk and branches, to the astonishment and admiration of the observer.—*Am. Ed.*

I hold a stone in my hand; if I let it go, it falls to the ground, and would fall still farther were there an aperture in the earth. While I write, my paper would fall to the ground were it not supported by the table. The same law applies to every body with which we are acquainted. There is not one that would not fall to the ground if it were not supported, or stopped by the way.

The cause of this phenomenon, or of this propensity of all bodies, is denominated *gravity*. When it is said that bodies are heavy, or possess gravity, we mean that they have a propensity to fall downward, and actually would fall if we remove what before supported them.

The ancients were little acquainted with this property. They believed that there were bodies which had naturally a tendency to rise, such as smoke and vapours; and such bodies they termed light, to distinguish them from those which have a tendency to fall. But it has been discovered by experiment that it is the air which raises these substances aloft; for in a space void of air, it is well known, by means of the air-pump, that smoke and vapours descend as well as stone, and that these substances are, of their own nature, heavy, like others. When, therefore, they rise into the air, the same law acts upon them which acts upon a log of wood plunged into the water. Notwithstanding its gravity, it springs up as soon as you leave it to itself, and swims, because it is not so heavy as water; and in virtue of a general rule, all bodies rise in a fluid of more gravity than themselves.

If you throw a piece of *iron*, of *copper*, of *silver*, and even of *lead*, into a vessel full of *quicksilver*, they swim on the surface; and if you force them down, they reascend when left to themselves. Gold alone sinks, because it is heavier than quicksilver.* And

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* Platinum is still heavier.—*Am. Ed.*

since there are bodies which rise in water and in other fluids, notwithstanding their gravity, for this reason merely, that they are not so heavy as water or those other fluids; it is not at all surprising that certain bodies, less weighty than air, such as smoke and vapours, should rise in it.

I have already remarked that air itself possesses gravity, and that by means of this gravity it supports the mercury in the barometer. When, therefore, it is affirmed that all bodies are heavy, it is to be understood that all bodies, without a single exception, would fall downward in a vacuum. I might venture to add, that they would fall with an equal degree of rapidity; for a feather and a piece of gold descend with equal velocity in an exhausted receiver.

It might be objected to this general property of body, that a shell discharged from a mortar does not at once fall to the ground, like a stone which I let drop from my hand, but mounts into the air. It cannot, however, be inferred that the shell has no gravity; for it is evident that the strength of the powder hurls the bomb aloft, and but for this, it would, without doubt, immediately fall to the ground. And we see, in fact, that it does not continue always to ascend, but as soon as the force which carries it upward is exhausted, down it comes with a rapidity that crushes every thing it meets—a sufficient proof of its gravity.

When, therefore, it is affirmed that all bodies are heavy, no one means to deny that they may be stopped, or that they may be thrown aloft; but this is effected by an external power; and it remains indubitably certain that all bodies whatever, as soon as left to themselves, at rest or without motion, will assuredly fall when no longer supported. There is a cellar under my apartment, but the floor supports me, and preserves me from falling into it. Were the floor suddenly to crumble away, and the arch of

the cellar to tumble in at the same time, I must infallibly be precipitated into it, because my body is heavy, like all other bodies with which we are acquainted. I say, *with which we are acquainted*, for there may, perhaps, be bodies destitute of weight; such as, possibly, light itself,* the elementary fire, the electric fluid, or that of the magnet: or such as the bodies of angels which have formerly appeared to men. A body like this would not fall downward, though the floor were suddenly to be removed from under it, but would move as firmly through the air as on the earth.

Except these bodies, the gravity of which is not yet confirmed by experiment, gravity may be considered as a general property of all the bodies which we know, in virtue of which they all have a tendency to fall downward, and actually do so when nothing opposes their descent.

23d August, 1760.

LETTER XLVI.

Continuation. Of Specific Gravity.

You have just seen, that gravity is a general property of all the bodies with which we are acquainted, and that it consists in the effect of an invincible force, which presses them downward.

Philosophers have warmly disputed, whether there actually exists a power which acts in an invisible manner upon bodies; or whether it be an internal quality inherent in the very nature of the bodies, and, like a natural instinct, constraining them to descend. The question amounts to this: If the cause of gravity is to be found in the very nature of every

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* The author must here mean the ether whose motions, on his theory, produce light.—*Am. Ed.*

body, or if it exists without it, so that were this extrinsic power to fail in its operation, the body would cease to be heavy. Before we attempt a solution of this, it will be necessary to examine more carefully all the circumstances connected with gravity.

I remark, first, that when you support a body to prevent its falling, if it rests on a table, its pressure is equal to the force with which it would tend to fall; and if a thread is affixed to it, by which it may be suspended, the thread is stretched by that force; in other words, by the gravity of that body; so that, if the thread were not of a certain strength, it would break. We see, then, that all bodies exercise a degree of force on the obstacles which support them, and prevent their falling; and that this action is precisely the same as that which would make the body descend if it were at liberty. When a stone is laid upon a table, the table is pressed by it. You have but to put your hand between the stone and the table to be sensible of this force, which may be increased to such a degree as even to crush the hand. This force is called the gravity of the body; and it is clear, that the weight or the gravity of every body signifies the same thing, both denoting the force with which that body is pressed downward, whether this force exists in the body itself, or out of it.

We have an idea too clear of the weight of bodies, to make it necessary to dwell longer on the subject. I only remark, that when two bodies are joined together, their weight too is added, so that the weight of the compound is equal to the sum of the weight of the parts. From this we see that the weight of bodies may be very different. We have also the certain means of exactly measuring and comparing them, by the help of a balance, which has the property of resting in equilibrium, when the bodies, put in its two scales, are of equal gravity. In order to make this comparison, we agree on some fixed measurement, of a certain determinate weight, such as a pound, and, by means of a good balance, all bodies may be weighed, and their gravity ascertained, according to the number of pounds which they contain. A body too great to be put into the scale of a balance may be divided, and the parts being weighed separately, you have only to add the particulars. The weight of a whole house, however large, may be thus ascertained.

You must, no doubt, have frequently remarked, that a small piece of gold weighs as much as a piece of wood greatly superior in size—a proof that the gravity of bodies is not always regulated by their magnitude; a very small body may be of great weight, while a very large one may be light. Every body, then, is susceptible of two measurements, entirely different from each other. The one determines its magnitude or extent, called likewise its size; this measurement belongs to the province of geometry, which teaches the method of measuring the magnitude or extent of bodies. The other mode of measurement, by which their weight is determined, is totally different, and serves to distinguish the nature of the different substances of which bodies are formed.

You can easily conceive several masses of different substances, all of the same magnitude or extent; each, for example, of a cubic figure, whose length, breadth and height shall be a foot. Such a mass, if it be of gold, would weigh 1330 pounds; if of silver, 770 pounds; if of iron, 500 pounds; and if of water, only 70 pounds; were it of air, it would weigh no more than the twelfth part of a pound. From this you see that the different substances of which bodies are composed vary considerably in respect of gravity.

To express this difference, we employ certain terms, which might appear equivocal, if they were not perfectly understood. Thus, when it is said, that *gold* is heavier than *silver*, it is not to be understood that a pound of gold is heavier than a pound of silver; for a pound of whatever substance is always a pound, and has always precisely the same weight; but the meaning is, that having two masses of the same size, the one gold and the other silver, the weight of the mass of gold will exceed that of the silver. And when it is said that gold is 19 times heavier than water, we mean, that having two equal masses, the one of gold, the other of water, that which is of gold will have 19 times the weight of that which is of water. When we thus express ourselves, we say nothing of the absolute weight of bodies, we only speak by way of comparison, and with a reference always to masses of an equal size. Neither is it of importance whether the size be great or small, provided they be equal.

25th August, 1760.

LETTER XLVII.

Terms relative to Gravity, and their true Import.

Gravity, or weight, seems so essential to the nature of bodies, that it is almost impossible to form the idea of a body divested of this quality. And its influence is so universal in all our operations upon body, that we must in every instance pay attention to its gravity or weight. As to our own persons, whether we stand, sit, or lie, we continually feel the effect of the gravity of our own body: we could never fall if the body were not, as well as all its parts, endowed with this force. Language itself is regulated according to this property of bodies. The place towards which a body tends in its descent we term *low*, and the opposite direction from the body we term *high*.

It must be remarked, that when a body, in falling, is at perfect liberty, it always descends in a straight line, pursuing which, its direction is said to be downwards. This line is likewise called *vertical*, by which term we always mean a straight line, drawn from high to low; and if we conceive this line produced upward, till it reaches heaven, we call that point in the heavens our *zenith*—an Arabian word, denoting that point in the heavens which is directly over our head. You comprehend, then, that a vertical line is that straight line in which a body falls, when no longer supported. When you affix a thread to any body, holding it fast at the other end, that thread will be stretched out into a straight line, and that line will be vertical. Masons employ a small cord, with a leaden ball at one end, which they call a *plummet*, to direct the perpendicularity of the walls which they raise; for these, to be solid, must be vertical.

All the floors of a house ought to be so level that the vertical line shall be perpendicular to them; the floor, in that case, is said to be horizontal; and you will please to remember, that a horizontal plane is always that to which the vertical line is perpendicular. When you are in a perfect plane, bounded by no mountain, its extremities are termed the *horizon* —a Greek word, which signifies the boundary of sight; and this plane then represents a horizontal plane, just as the surface of a lake.

We make use of still another term to express what is horizontal. We say that such a surface or line is *level*. We likewise say, that two points are on the level, when a straight line passing through these two points is horizontal, so that the vertical, or plumb-line, shall be perpendicular to it. But two points are not on the level when the straight line drawn through these points is not horizontal; for then one of them is more elevated than the other.

This is the case with rivers; their surface has a declivity; for were it horizontal, the river would be

stagnant, and run down no longer, whereas all rivers are continually flowing towards places less elevated. There are instruments by means of which we can ascertain whether two points are on the same level, or which is the higher, and by how much. This instrument is called a *level*, and the application of it is called the art of levelling.

Were you to draw a straight line from any point in your apartment at Berlin to a given point in your apartment at Magdeburg, you might, by means of such an instrument, ascertain whether this line were horizontal, or whether one of these points were more or less elevated than the other. I believe the point at Berlin would be more elevated than that at Magdeburg: and I found this opinion on the course of the rivers Sprée, Havel, and Elbe. As the Sprée runs into the Havel, it must of course be higher; and, for the same reason, the Elbe must be lower than the Havel: Berlin therefore stands higher than Magdeburg, provided you compare two points at an equal degree of elevation from the ground; for, were a straight line to be drawn from the street pavement at Berlin to the pinnacle over the dome at Magdeburg, that line would perhaps be horizontal.

Hence you see how useful the art of taking levels is, when the conducting of water is concerned. For as water can run only from a more to a less elevated situation, before digging a canal you must be well assured that one of the extremities is more elevated than the other, and this is discovered by taking the level.

In building a city, the streets should be so disposed, as that, by means of a declivity on one side, the water may run off. It is otherwise in the construction of houses, the floors of which should be perfectly horizontal, and without the smallest declivity, because there is no water to be discharged, except in the floors of stables, which are constructed with a gentle declivity. Astronomers take great pains to have the floors of their observatories perfectly level, to correspond with the real horizon in the heavens. The vertical line, produced upward, marks the zenith.

27th August, 1760.

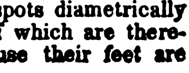
LETTER XLVIII.

Reply to certain Objections to the Earth's Spherical Figure, derived from Gravity.

You know well, that the figure of the earth is nearly that of a globe. It has, indeed, been demonstrated, that its form is not perfectly spherical, but somewhat flattened towards the poles. The difference, however, is so trifling, that it does not at all affect the object I have in view. Neither does the difference of mountain and valley excite any solid objection to its globular figure; for its diameter being 7912 English miles, the highest mountains being about five English miles in height, sink into nothing, compared to this prodigious mass.

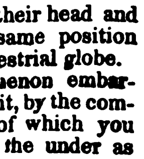
The ancients had a very imperfect notion of the real figure of the earth. It was in general considered as a huge massy substance, A B C D, *Fig.* 28, flattened above as A B, and covered partly with earth, partly with water. According to their idea, the surface A B alone was habitable; and it was impossible to go beyond the points A and B, which they considered as the extremities of the world. When, in the progress of discovery, it was found that the earth was nearly spherical, and universally habitable, so that there were upon the globe spots diametrically opposite to us, the inhabitants of which are therefore called our *antipodes*, because their feet are

Fig. 28.



turned directly towards ours—this opinion met with such violent contradiction, that certain fathers of the church represented it as a dreadful heresy, and thundered out anathemas against all who believed in the existence of the antipodes. A man, however, would now pass for an idiot who would call it in question; especially since the opinion has been confirmed by the experience of navigators, who have frequently sailed round the globe. But another difficulty here presents itself, the solution of which must assist us in discovering the real direction of gravity.

Fig. 29.



If the circle A B, *Fig.* 29, say they, represent the earth, and we are at A, our antipodes will be diametrically opposite at B. As we, then, have the head upward and the feet downward, our antipodes must have the feet upward and the head downward, supposing these words to indicate the same direction as when we pronounce the same words at the place where we are. For navigators who have made the circuit of the globe, observe, that their head and feet had throughout maintained the same position relatively to the surface of the terrestrial globe.

Some persons, whom this phenomenon embarrassed, formerly thought of explaining it, by the comparison of a globe, over the surface of which you see flies and other insects crawl on the under as well as the upper part. But they did not consider that the insects on the dependent surface adhere to it by their claws, and without this assistance would presently fall off. The antipode, then, must have his shoes furnished with hooks to hold him fast to the surface of the earth; but though he has none, he does not fall, any more than we do. Besides, as we imagine ourselves to be on the uppermost surface of the earth, the antipode has the same idea of his situation, and considers us as undermost.

But the whole phenomena are easily accounted for on the hypothesis which experience has demonstrated, that the direction of gravity is sensibly perpendicular to the surface of the earth, at every point of that surface; that it varies at these different points; and that at those which are antipodes to each other it must be exactly opposite. The terms *upward* and *downward*, therefore, do not express an invariable direction, but the direction of gravity, wherever it is. Our antipodes have their heads *downward* only with relation to us, but not with relation to themselves; they, as well as we, are in the position which the power of gravity constrains them to preserve; and that position is similar, relatively to the surface of the earth. You had, undoubtedly, no need of this explanation; but there was a time, and it is not long elapsed, when it would have been necessary even to persons who were then honoured with the appellation of the learned.

28th August, 1760.

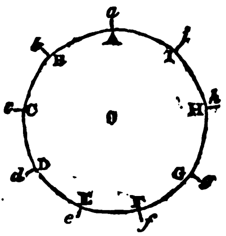
LETTER XLIX.

True Direction and Action of Gravity relatively to the Earth.

Though the surface of the earth is unequal, because of the mountains and valleys which overspread it, it is, however, perfectly level wherever there is sea; the surface of water being always horizontal, and the vertical line, in the direction of which bodies fall, being perpendicular to it. If, then, the whole globe were covered with water, at whatever spot of the surface a person was, the vertical line would be perpendicular to the surface of the water.

Thus, the figure A B C D E F G H I, *Fig.* 30, representing the earth, its surface being everywhere horizontal; at A the line *a* A will be vertical; at B the line *b* B; at C the line *c* C; at D the line *d* D; at F the line *f* F; and so of the rest. Now, at every place the vertical line determines what is to be denominated *upward* or *downward;* to persons at A, then, the point A is downward, and the point *a* upward; and to persons at F, the point F will be downward, and the point *f* upward, and so for every other spot on the surface of the earth. All these vertical lines *a* A, *b* B, *c* C, *d* D, &c. are likewise named the directions of gravity, or weight, because bodies universally descend in the direction of these lines; thus, a body left to itself at *g* would fall in the direction of the line *g* G. Hence it is evident, that bodies universally must fall towards the earth, and that perpendicularly to the surface of the earth, or rather of the water, if it were water.

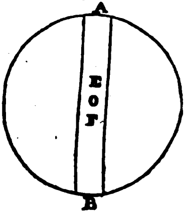
Fig. 30.



At whatever place of the earth, therefore, you may happen to be, as bodies fall there towards its surface, we call *downward* that which is directed towards the earth, or is nearest to it; and *upward* what is placed in the opposite direction, or is farthest from the earth: and, universally, men having their feet pressed to the earth, their feet will be downward and their heads upward. If the earth were a perfect globe, all the vertical lines *a* A, *b* B, *c* C, being produced inwardly, would meet at the centre of the globe, which is likewise that of the earth; and for this reason we say that bodies universally tend towards the centre of the earth. Thus, wherever you are placed, when asked, what is downward?

the answer must be, what approaches nearest to the centre of the earth. In fact, were you to dig a hole in the earth, at whatever place, and to continue your labour incessantly, digging always downward and downward perpendicularly, you would at length reach the centre of the earth. You will remember how *Voltaire* used to laugh at the idea of a hole reaching to the centre of the earth, mentioned by *Maupertuis*. It is true, such a project could never be executed, as it would be necessary to dig to the depth of 3956 English miles; but there is no harm in supposing it, in order to discover what would be the result.

Fig. 31.



Let us suppose, then, such a hole, *Fig.* 31, to be dug at A, and continued beyond the centre of the earth O, the whole length of the diameter, as far as to our antipodes B, and that we were to descend along this aperture. Before arriving at the centre O, and having reached, for example, the point E, the centre of the earth O will there appear downward, and the point A upward; and, unless something supported us, we should fall towards O. But having passed beyond the centre, to F, for example, our gravity would then have a tendency towards O; this point, and much more the point A, would appear downward, and the point B upward. Thus the terms upward and downward would suddenly change their signification, though we should have passed from A to B, in the direction of a straight line.

As long as we are on the passage from A to O, we are descending; but in going from O to B, we are actually rising, for we are removing from the centre of the earth—our own gravity being always directed towards that point; so that, if we were to fall, whether from E or from F, we should always fall towards the centre of the earth. Our antipode at B, if he wanted to pass from B to A, would be in precisely the same situation. From B to the centre O he would have to descend; but from O to A it would be all an ascent. These considerations lead us thus to define gravity or weight: It is a power by which all bodies are forced towards the centre of the earth. The same body which, being at A, is forced in the direction A O, if transported to B, will be forced, by the power of gravity, in the direction B O, which is directly opposite to the other. By the direction of gravity, then, we everywhere regulate the signification of the terms *upward* and *downward*, *rise* and *descend*, as gravity or weight has a very essential influence on all our operations and enterprises, and as even our own bodies are animated by it to such a degree as universally to feel its effects.

29th August, 1760.

LETTER L.

Different Action of Gravity with respect to certain Countries and Distances from the Centre of the Earth.

You are now sensible that all bodies are forced directly towards the centre of the earth, and perpendicularly to its surface, by their gravity: the perpendicular lines at the surface of our globe are accordingly considered as the directions of the power of gravity.

With strict propriety is the term *power* applied to gravity, as every thing capable of putting a body in motion is expressed by that name. Thus we ascribe power to horses, because they are able to draw along a chariot; or to the current of a river, or to the wind, because by their means mills may be put in motion. There can be no doubt, therefore, that gravity is a power, as it forces bodies downward: and we are abundantly sensible of the effect of this power, by the pressure which we feel when we carry a load.

Now, in every power two things are to be considered: first, the direction in which it acts or forces along bodies; and secondly, its quantity, which is estimated by the effect it produces. As to the direction of gravity, it is sufficiently known; for we are sure that it forces all bodies towards the centre of the earth, or, which amounts to the same thing, that it acts perpendicularly to the surface of our globe.

It remains, therefore, that we examine its quantity. This power is always determined by the weight of every body; and as bodies differ greatly with respect to weight, those which are heaviest are likewise forced down with the greatest violence. It has been asked, Whether the same body, transported to a different place of the globe, preserves always the same weight? I speak of bodies which lose nothing by evaporation. It has been demonstrated by undoubted experiments that the same body weighs somewhat less towards the equator than towards the poles of the earth.

It will readily occur to you that it is impossible to ascertain this difference by the exactest balance, because the standard weights employed for determining the weight of matter in bodies undergo the same variation. Thus, a mass which with us might weigh 100 pounds, being transported to the equator, would still nominally be 100 pounds weight, but the effort will be somewhat less than here. This variation has been discovered by the effect itself of the power of gravity, which is the velocity of the descent; for it is found that the same body under the equator does not descend with so great velocity as in high latitudes. It is certain, therefore, that the same body, being transported to different places of the earth, undergoes a little change as to weight.

Let us now return to the aperture made in the earth through its centre; it is clear that a body at the very centre must entirely lose its gravity, as it could no longer move in any direction whatever, all those of gravity tending continually towards the centre of the earth. Since, then, a body has no longer gravity at the centre of the earth, it will follow, that in descending to this centre its gravity will be gradually diminished; and we accordingly conclude that a body penetrating into the bowels of the earth loses its gravity, in proportion as it approaches the centre. You must be sensible, then, that neither the intensity nor the direction of gravity is a consequence from the nature of every body, as not only its intensity is variable, but likewise its direction, which, on passing to the antipodes, becomes quite contrary.

Having travelled in idea to the centre of the earth, let us return to its surface, and ascend to the summit of the loftiest mountains. We shall observe there no sensible change in the gravity of bodies, though there is very good reason to believe that the weight of a body diminishes in proportion as it removes from the earth. You have but to imagine a body gradually removing from our globe, till it reached the sun, or one of the fixed stars,—it would be ridiculous to think that such a body must fall back to the earth, as it is almost a nothing compared to these stars. Hence, then, it may be concluded that a body in removing from the earth must undergo a diminution of gravity, which will become smaller and smaller, till at last it wholly disappear.

There are reasons, however, which demonstrate that a body removed to the distance of the moon will still have some weight, though 3600 times less than it had on the earth. Let us conceive such a body to weigh 3600 pounds on the earth, no one, surely, is capable of supporting it here; but convey it to the distance of the moon, and I shall engage to support it with one of my fingers, for then it will weigh only one pound; and if farther removed it would weigh still less. We are certain, therefore, that gravity is a power which forces all bodies towards the centre of the earth, that this power acts with the greatest force at the surface of the earth, and is diminished in proportion as it removes from thence, whether by penetrating towards the centre or rising above the surface of the globe. I have still much to say on this subject.

30*th August*, 1760.

LETTER LI.

Gravity of the Moon.

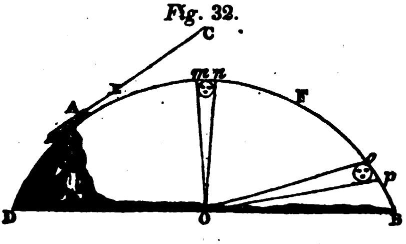
I HAVE said that a terrestrial body placed at the distance of the moon would be reduced to the 3600th part of its weight, or, in other words, would be forced towards the centre of the earth with a power 3600 times less than it has at the surface of the globe. This power, however, would be sufficient to make it descend to the earth, if it were no longer supported. It is true we are incapable of proving this by any experiment, as no means exist of raising ourselves to such a height. There is, however, a body at that height—the moon: she must therefore be subject to this effect of gravity, and yet we see she does not fall to the earth.

To this I answer, that if the moon were at rest, she would certainly fall; but the rapid motion which carries her along prevents her from falling. There are experiments which prove the solidity of this answer. A stone dropped from the hand, without having any motion impressed upon it, falls immediately in the direction of a straight vertical line; but if you throw this stone, impressing on it a motion which forces it out of that direction, it does not fall immediately downward, but moves in a curve line before it reaches the earth; and this will appear more sensibly in proportion to the velocity impressed upon it.

A cannon-ball discharged in a horizontal direction does not come to the earth till it has got to a considerable distance; and were it fired from the top of a high mountain, it might perhaps fly several miles before it reached the ground. If the direction of the cannon is farther elevated, and the quantity and strength of the powder increased, the ball will be carried much farther. This might be carried so far that the ball should not light till it had reached the antipodes: nay, farther still, till it should not fall at all, but return to the place where it was shot off; and thus perform a new tour round the globe. It would thus be a little moon, making its revolutions round the earth, like the real moon.

You will now please to reflect on the height of the moon, and the prodigious velocity with which she moves, and you will no longer be surprised that she should not fall to the earth, though forced by gravity towards its centre. There is another reflection which will place this in a clearer light. We have only to consider the path described by a stone thrown, or a cannon-ball shot off, in an oblique direction. It is always a curve, such as represented in the annexed figure.

Fig. 32.



Let A be the summit of a mountain from which the cannon-ball is fired off, which, after having moved in the direction A E F B, falls to the ground at B; and the path which it describes is a curve line. I remark, then, that if the ball were not heavy, that is, if it were not forced towards the earth by the power of gravity, it would not fall, though left to itself, as gravity is the only cause of its descent; much less, being fired off at A, as represented in the figure, would it ever fall to the ground. Hence we see it is gravity that brings it down to the ground, after having described the curve A E F B; gravity, therefore, directs its path in the curve A E F B; and if it were destitute of gravity, the ball would not describe a curve, but proceed forward in the direction of the straight line A C, the direction in which it was fired off.

This being laid down, let us attend to the moon, which assuredly does not move in a straight line; her path must of necessity be a curve, as she always preserves nearly the same distance from us, and that curve almost a circle, such as you would describe round the earth, with a radius equal to the moon's distance.

It is very reasonable to demand, why the moon does not move in a straight line. But the answer is obvious; for as gravity occasions the curved direction of the path pursued by a stone thrown, or a cannon-ball fired off, there is good ground for maintaining, that gravity acts likewise upon the moon, forcing her towards the earth; and that this gravity occasions also the curved direction of her orbit. The moon, then, has a certain weight—she is, of consequence, forced towards the earth; but this weight is 3600 times less than it would be at the surface of the earth. This is not merely a probable conjecture, but a truth demonstrated. For this gravity being supposed, we are enabled to determine, on the most established mathematical principles, the path which the moon must pursue; and this is found perfectly to agree with that in which she actually does move; and this is a complete demonstration of the truth of the assertion.

1st September, 1760.

LETTER LII.

Discovery of Universal Gravitation by Newton.

Gravity, then, or weight, is a property of all terrestrial bodies, and it extends likewise to the moon. It is in virtue of gravity that the moon presses towards the earth; and gravity regulates her motion just as it directs that of a stone thrown, or of a cannon-ball fired off.

To *Newton* we are indebted for this important discovery. This great English philosopher and geometrician happening one day to be lying under an apple-tree, an apple fell upon his head, and suggested to him a multitude of reflections. He readily conceived that gravity was the cause of the apple's falling, by overcoming the force which attached it to the branch. Any person whatever might have made the same reflection; but the English philosopher pursued it much further. Would this force have always acted upon the apple, had the tree been a great deal higher? He could entertain no doubt of it.

But had the height been equal to that of the moon? Here he found himself at a loss to determine whether the apple would fall or not. In case it should fall, which appeared to him, however, highly probable, since it is impossible to conceive a bound to the height of the tree at which it would cease to fall, it must still have a certain degree of gravity forcing it towards the earth; therefore, if the moon were at the same place, she must be pressed towards the earth by a power similar to that which would act upon the apple. Nevertheless, as the moon did not fall on his head, he conjectured that motion might be the cause of this, just as a bomb frequently flies over us without falling vertically.

This comparison of the motion of the moon to that of a bomb, determined him attentively to examine this question; and, aided by the most sublime geometry, he discovered that the moon in her motion was subject to the same laws which regulate that of a bomb, and that if it were possible to hurl a bomb to the height of the moon, and with the same velocity, the bomb would have the same motion as the moon, with this difference only, that the gravity of the bomb at such a distance from the earth would be much less than at its surface.

You will see, from this detail, that the first reasonings of the philosopher on this subject were very simple, and scarcely differed from those of the clown; but he soon pushed them far beyond the level of the clown. It is, then, a very remarkable property of the earth, that not only all bodies near it, but those also which are remote, even as far as to the distance of the moon, have a tendency towards the centre of the earth, in virtue of a power which is called gravity, and which diminishes in proportion as bodies remove from the earth.

The English philosopher did not stop here. As he knew that the other planets are perfectly similar to the earth, he concluded, that bodies adjacent to each planet possess gravity, and that the direction of this gravity is towards the centre of the planet. This gravity might be greater or less there than on the earth; in other words, that a body of a certain weight with us, transported to the surface of any planet, might there weigh more or less.

Finally, this power of gravity of each planet extends likewise to great distances around them; and as we see that Jupiter has four satellites, and Saturn five, which move round them just as the moon does round the earth, it could not be doubted that the motion of the satellites of Jupiter was regulated by their gravity towards the centre of that planet, and that of the satellites of Saturn by their gravitation towards the centre of Saturn. Thus, in the same manner as the moon moves round the earth, and their respective satellites move round Jupiter and Saturn, all the planets themselves move round the sun. Hence *Newton* drew this illustrious and important conclusion: That the sun is endowed with a similar property of attracting all bodies towards its centre, by a power which may be called *solar gravity.*

This power extends to a prodigious distance around him, and far beyond all the planets: for it is this power which modifies all their motions. The same great philosopher discovered the means of determining the motion of bodies from the knowledge of the power by which they are attracted to a centre; and as he had discovered the powers which act upon the planets, he was enabled to give an accurate description of their motion. In truth, before he arose the world was in a state of profound ignorance respecting the motion of the heavenly bodies; and to him alone we are indebted for all the light which we now enjoy in the science of astronomy.

It is astonishing to think how much of their progress all the sciences owe to an original idea so very simple. Had not *Newton* accidentally been lying in an orchard, and had not that apple by chance fallen on his head, we might perhaps still have been in the same state of ignorance respecting the motions of the heavenly bodies, and a multitude of other phenomena depending upon them. This subject undoubtedly is altogether worthy of your attention, and shall therefore be resumed in a future Letter.*

3d September, 1760.

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* Too much is doubtless ascribed here to the falling of the apple. To a mind like Newton's, the laws of gravitation would have been deduced from considerations suggested by the general phenomena of falling bodies.—*Am. Ed.*

LETTER LIII.

Continuation. Of the Mutual Attraction of the Heavenly Bodies.

The Newtonian System, you will easily believe, made at first a great noise, and with good reason, as no one had hitherto hit upon a discovery so very fortunate, and which diffused at once such clear light over every branch of science. It has been expressed by several names, of which it is proper you should be informed, because it is frequently the subject of conversation.

It has been denominated the system of universal gravitation; for *Newton* maintained, that not only the earth, but all the heavenly bodies in general, are endowed with this property—of attracting those which surround them with a power similar to that of weight or gravity; hence is derived the term *gravitation*. This power is, however, totally invisible; for we see nothing acting upon bodies, and pressing them towards the earth, and still less towards the heavenly bodies.

The loadstone, by which iron and steel are attracted without our being able to discern the cause, presents a phenomenon somewhat similar. Though it be now certain that this is produced by a substance extremely subtile, which penetrates through the pores of the loadstone and of the iron, it may, however, be affirmed, that the loadstone attracts iron, and that iron is attracted by it, provided this manner of speaking does not exclude the true cause. It may likewise be affirmed, then, that the earth attracts all bodies that are near it; nay, those which are at very great distances: and we may consider the weight or gravity of bodies as the effect of the attraction of the earth, which acts even upon the moon.

Again, the sun and all the planets are endowed with a similar power of attraction, which extends to all bodies. In conformity to this manner of speaking, we say that the sun attracts the planets, and that Jupiter and Saturn attract their respective satellites; hence *Newton's* system has likewise been denominated the system of *attraction*. As there can be no doubt that bodies very near the moon must likewise be pressed to it by a power similar to gravity, it may likewise be affirmed, that the moon too attracts adjoining bodies.

It was natural to suppose, that this attraction of the moon should extend as far as the earth, though it must be undoubtedly very feeble, as we have seen that of the earth upon the moon to be; now the same philosopher has placed this also beyond the reach of doubt, by demonstrating, that the flux and reflux of the waters of the sea, of which I shall take occasion to speak afterward, are caused by the attraction of the moon. It can no longer be doubted, therefore, that Jupiter and Saturn are reciprocally attracted by their respective satellites; and that the sun itself is subject to the attraction of the planets, though this attractive power be exceedingly small.

This is the origin of the system of universal attraction, in which it is maintained, and with good reason, that not only does the sun attract the planets, but is reciprocally attracted by each of them; nay, that all the planets exert their attractive power upon each other. The earth, then, is attracted, not only by the sun, but also by all the other planets, though their power be almost imperceptible compared to that of the sun.

You will easily comprehend, that the motion of a planet, which is attracted, not only by the sun, but by the other planets, in however small a degree, must be somewhat different from what it would have been were it attracted by the sun only; and that consequently the attractions of the other planets must cause some small derangement of that motion. Now these derangements are likewise confirmed by experience; and this has carried the system of universal attraction to the highest possible degree of certainty, so that no one now presumes to dispute its truth.

I must likewise remark, that comets too are subject to this law; that they are principally attracted by the sun, whose action regulates their motion; but that they likewise feel the attractive power of all the planets, especially when they are not very distant from them. It is a general rule, as we shall see afterward, that the attraction of all the heavenly bodies diminishes in proportion to the distance, and increases in proportion to the nearness. Now comets likewise are endowed with a power by which other bodies are attracted towards them, and so much the more sensibly as they approach nearer. When, therefore, a comet passes somewhat more closely to a planet, it may derange the motion of that planet by its attractive power; and its own will likewise be disturbed by that of the planet. These consequences are verified by real observation.

Examples might be adduced to prove that the motion of a comet has been deranged by the attraction of the planets near which it happened to pass; and that the motion of the earth, and of the other planets, has already undergone some derangement from the attraction of comets.

The fixed stars, being bodies similar to the sun, are likewise endowed, no doubt, with an attractive power; but their enormous distance prevents our feeling any sensible effect from it.

5th September, 1760.

LETTER LIV.

Different Sentiments of Philosophers respecting Universal Gravitation. The Attractionists.

It is established, then, by reasons which cannot be controverted, that a universal gravitation pervades all the heavenly bodies, by which they are attracted towards each other; and that this power is greater in proportion to their proximity.

This fact is incontestable; but it has been made a question, whether we ought to give it the name of *impulsion* or *attraction*. The name undoubtedly is a matter of indifference, as the effect is the same. The astronomer, accordingly, attentive only to the effect of this power, gives himself little trouble to determine whether the heavenly bodies are impelled towards each other, or whether they mutually attract one another; and the person who examines the phenomena only is unconcerned whether the earth attracts bodies, or whether they are impelled towards it by some invisible cause.

But in attempting to dive into the mysteries of nature, it is of importance to know if the heavenly bodies act upon each other by impulsion, or by attraction; if a certain subtile invisible matter impels them towards each other; or if they are endowed with a secret or occult quality, by which they are mutually attracted. On this question philosophers are divided. Some are of opinion, that this phenomenon is analogous to an impulsion; others maintain, with *Newton*, and the English in general, that it consists in attraction.

It must be observed, that the terms *attract* and *draw* are not perfectly synonymous; that accordingly it is not to be supposed there is an intermediate body between the sun and the earth.

The English, and those who have adopted the same opinion, explain it in this manner: They maintain, that the quality of mutual attraction is proper to all bodies; that it is as natural to them as magnitude; and that it is a satisfying solution of the question that the Creator willed this mutual attraction of bodies. Had there been but two bodies in the universe, however remote from each other, they would have had from the first a tendency towards each other, by means of which they would have in time approached and united. Hence it follows, that the greater a body is, the more considerable is the attraction which it exerts upon others; for as this quality is essential to matter, the more of it any body contains, the greater is its attractive force.

As the sun, therefore, considerably surpasses all the planets in magnitude, its attractive force must be much greater than theirs. They likewise remark, that the mass of Jupiter being much greater than that of the earth, the attractive force which he exercises over his satellites is much more powerful than that with which the earth acts upon the moon.

According to this system, the gravity of bodies on the earth is the result of all the attractions exercised upon them by the particles of our globe; and if it contained more matter than it actually does, its attraction would become more powerful, and the gravity of bodies would be increased. But if, on the contrary, the mass of the earth should happen by some accident to be diminished, its attractive force too would be diminished, as well as the gravity of bodies at its surface.

It has been objected to these philosophers, that, on their hypothesis, any two bodies whatever at rest, for instance, on a table, must attract each other, and consequently approach. They admit the consequence; but they insist, that in this case the attraction would be too small to produce any sensible effect; for if the whole mass of the earth, by its

attractive force, produces in every body only that effect which we perceive in the weight of a body, a mass many millions of times smaller than the earth will produce an effect as many times smaller.

It must readily be admitted, that if the weight of a body became many millions of times less, the effect of gravity upon it must be reduced to almost nothing: attraction, therefore, cannot be perceptible, except in bodies of very great magnitude. The partisans of the system of gravitation, therefore, are not vulnerable on this side; and they produce in support of their opinion an experiment made in Peru by the French academicians,[*] in which they perceived the effect of a slight attraction of a prodigious mountain on adjacent bodies. In adopting, therefore, the system of attraction, we need be under no apprehension of its leading us to false consequences; and it has hitherto been always confirmed by the new facts which have been discovered.

7th September, 1760.

LETTER LV.

Power by which the Heavenly Bodies are mutually attracted.

You are well acquainted with the property of the loadstone, that of attracting iron. You have seen small bits of iron and steel, such as needles, when placed near the loadstone, move to it with a force proportioned to their proximity. As you see nothing that impels them towards the loadstone, we

[*] Dr. Maskelyne has more recently found, that a deviation of 5″.8 was produced by the attraction of the mountain called *Schehallien*, in Scotland, the double effect being about 11″.6. Mr. Cavendish also succeeded in measuring the mutual attraction of balls of lead, by means of an apparatus for that purpose. Hence it was found that the mean density of the earth was about *five* times that of *water*.—*Ed.*

say that the loadstone attracts them, and this phenomenon we call *attraction*. It cannot be doubted, however, that there is a very subtile, though invisible matter, which produces this effect by actually impelling the iron towards the loadstone; but as modes of expression are regulated by appearances, it has become customary to say that the loadstone attracts iron.

Though this phenomenon be peculiar to the loadstone and iron, it is perfectly adapted to convey an idea of the signification of the word attraction, which philosophers so frequently employ. They allege, then, that all bodies, in general, are endowed with a property similar to that of the loadstone, and that they all mutually attract; but that this effect does not become perceptible unless they are very great, and cannot be perceived when they are small.

However great, for example, a stone may be, it exercises no sensible attraction on other bodies adjacent to it, because its power is too small. But if its mass were to increase, and to become many thousands of times greater, its effect would at length become perceptible. It has already been remarked, that, from actual observation, it was found that a lofty mountain in Peru had produced attraction, though indeed in a very small degree. A mountain still greater would produce, therefore, a more sensible attraction; and a body much greater, such as the whole globe, would attract others with a force proportionably greater; and this force would be precisely the gravity with which we see that they are actually impelled towards the earth.

According to this system, then, the gravity which obliges all bodies to descend is nothing else but the result of the attraction of the whole mass of the earth. If this mass were greater or less, the gravity or weight of bodies would be proportionably greater or less. Hence it follows, that all the other great bodies in the universe, as the sun, the planets, and the moon, are endowed with a similar attractive power; but greater or less in proportion as they themselves are so.

As the sun is many thousands of times greater than the earth, his attractive power exceeds that of the earth so many thousand times. The mass of the moon is calculated to be forty times less than that of the earth; it will follow, that her attractive force is so many times less: and the same rule applies to all the heavenly bodies.

9th September, 1760.

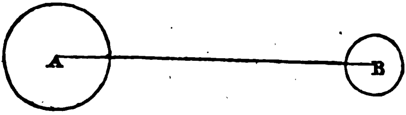
LETTER LVI.

The same Subject continued.

In virtue of the system of attraction, or universal gravitation, each of the heavenly bodies attracts all the rest, and is reciprocally attracted by them.

In order to form a judgment of the force with which these bodies attract the others, we have only to consider two bodies whose attraction is mutual. And here we must attend to three things; first, to the body attracting; secondly, to the body attracted; and, finally, to their distance: for on these three circumstances the attractive power depends.

Fig. 33.



Let A, *Fig.* 33, be the attracting body, and B the body attracted; both of them spherical, the heavenly bodies being nearly of this figure. Take for their distance that of their centres A and B, that is, the straight line A B. Now, with respect to the mass of the attracting body A, it must be remarked, that the greater it is, the greater also will be its power to attract the body B. Consequently, if A were twice as great as B, this last would feel an attraction twice as powerful exercised over it by the other; if it were three times as great the effect would be triple, and so on—always supposing the distance of their centres to be the same.

If, then, the earth contained more or less matter than it actually does, it would attract all adjacent bodies with greater or less force, or their weight would be increased or diminished. And as the earth itself is attracted by the sun, the same thing might be affirmed as to it, should the mass of that luminary happen to change. As to the attracted body B, supposing the attracting body A and the distance A B to continue the same, it is to be remarked, that the greater or smaller its mass is, the greater or less, also, is the power with which it is attracted towards A. Thus, if the body B were twice as great, it would be attracted towards A with double the force; if three times greater, with triple the force, and so on.

In order more clearly to elucidate this remark, we have only to substitute the earth in the place of the attracting body A; then the force with which the body B is attracted is nothing else but the weight of that body. Now, it is demonstrated that the greater or smaller the body A is, the greater or less also is its gravity; hence it follows, that while the attracting body A and the distance A B continue the same, the attraction which B feels precisely follows the magnitude of that body. To express this circumstance, mathematicians employ the term *proportional;* thus, they say the body B is attracted by the body A with a force proportional to its mass; the meaning of which is, that if the mass of body B were twice, thrice, or four times greater, the attractive power would be precisely so many times increased. Thus, with respect to the attracting body A, they say, that the power which it exercises over the body B is proportional to its mass, so long as that of B and the distance A B continue the same.

I must further observe, that when we speak of the quantity of the attracting body A, or of the attracted body B, we mean the quantity of matter which each contains, and not their magnitude merely. You will recollect, that bodies differ considerably in this respect, and that there are some, which, in a very small compass, contain a great deal of matter, gold, for example, while others, such as air, contain very little in a great space. When, therefore, we here speak of bodies, we are always to be understood as referring to the quantity of matter which they contain: this is what we mean by their mass.

All that now remains is to examine the third circumstance, namely, the distance A B of the two bodies, supposing them to continue always the same. It must be observed, that as the distance A B increases, the attraction diminishes; and that as they approach nearer, it increases: but in conformity to a law which it is not so easy to express. When the distance becomes twice as great, the force with which the body B is attracted towards the body A will be twice two, or four times less; and for triple the distance, the attraction becomes three times three, that is nine times less. If the distance becomes four times greater, the power of attraction becomes four times four, that is sixteen times less, and so on. Finally, for a distance a hundred times greater, the power of attraction will be a hundred times a hundred, or ten thousand times less. From this it follows, that at very great distances it must become altogether imperceptible. And, reciprocally, when the distance A B is very small, the attraction may be very considerable, though the bodies may be of no great magnitude.

11th September, 1760.

LETTER LVII.

The same Subject continued.

I HAVE now demonstrated that when a body B is attracted by a body A, the power of attraction is proportional to the mass of the attracting body A, and to that of the attracted body B; but it depends to such a degree on the distance of these bodies, that if it should become twice, thrice, four, or five times greater, the power of attraction would become four, nine, sixteen, or twenty-five times less.

In order to ascertain the rule of these quantities, we must multiply into itself the number which marks how many times the distance is increased, and the product will show how many times less the power of attraction has become. To put this rule in its clearest light, it must be observed, that when we multiply a number into itself, the product resulting from it is called its *square*. Thus, to find these squares, we must multiply the numbers by themselves, as below.

	1	2	3	4	5	6	7	8	9	10
Multiplied by	1	2	3	4	5	6	7	8	9	10
Square	1	4	9	16	25	36	49	64	81	100

	11		12
Multiplied by	11	Multiplied by	12
Square	121	Square	144

It is clear, from this last example, that the square of number 12 is 144; and if you wish to know the square of any number whatever, say 258, you must multiply that number by itself, as in the following scheme:—

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  258
  258
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 2064
1290
516
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66564
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From which we see, that the square of 258 is 66,564; and the squares of all numbers whatever may be calculated in like manner.

As the distance of bodies, then, must be multiplied by itself, it is evident that the power of attraction diminishes as much as the square of the distance increases; or, that the square of the distance becomes as many times greater as the power of attraction is diminished.

In treating subjects of this nature, mathematicians employ expressions whose signification it is proper you should know, because they sometimes occur in the course of conversation. If the attractive power increased in proportion to the square of the distance, we would call it *proportionally* to the square of the distance; but as the direct contrary takes place, and as the attractive power diminishes as the square of the distance increases, we employ the term *reciprocally* to express this contrariety, saying, that the power is reciprocally proportional to the square of the distance. It is a geometrical mode of expression, the meaning of which you perfectly comprehend; and it refers to what I have just been attempting to explain.

In order to judge aright of the power which one body exercises over another, you have only to remark, that this power is, first of all, proportional to the mass of the attracting body: then to that of the body attracted; and finally, reciprocally to the square of their distance. Hence it is evident, that though the earth, and the other planets are likewise attracted towards the fixed stars, the power must be imperceptible, on account of their prodigious distance.

Supposing, therefore, the mass of a fixed star to be equal to that of the sun, at equal distances, the earth would be attracted towards it with a force as great as towards the sun; but as the distance of the fixed star is 400,000 times greater than that of the sun, the square of this number being 160,000,000,000, that is, a hundred and sixty thousand millions, the power with which it acts upon our globe is a hundred and sixty thousand millions of times less than that of the sun; and, consequently, too feeble to produce any perceptible effect. For this reason, the attractive power of the fixed stars does not at all affect the earth's motion, nor that of the planets and the moon: but it is that of the sun which chiefly regulates their motions, because his mass exceeds many thousands of times the mass of each planet.

When, however, two planets approach, so that their distance becomes less than that of the sun, their attractive power increases, and may become sufficiently perceptible to derange their motion. Such derangement has, in fact, been observed; and constitutes an irresistible proof of the system of universal gravitation. Accordingly, when a comet approaches very near to a planet, the motion of this last may be considerably affected by it.

13th September, 1760.

LETTER LVIII.

Motion of the Heavenly Bodies. Method of determining it by the Laws of universal Gravitation.

From what has been said respecting the power by which all the heavenly bodies mutually attract each other, proportionally to their mass and distance, you are enabled to comprehend how their motions may be determined, and the real place of each body, at any given time, accurately assigned.

In this astronomy consists; the object of which is an exact knowledge of the motions of the heavenly bodies, in order to be able to determine, for every instant of time, whether past or to come, the place in which each of them must be, and in what place of the heavens it must appear, whether viewed from the earth, or any other point whatever of the universe.

The science which treats of motion in general is named *mechanics*, or *dynamics*. Its object is to determine the motion of all bodies whatever, animated by whatever power. This science constitutes one of the principal branches of mathematics; and those who apply to it exert all their efforts to carry mechanics to the highest possible degree of perfection. The subjects about which this science is conversant are, however, so intricate, that there is hitherto no great ground of boasting of our progress in the investigation of them; and we must rest satisfied with advancing step by step. Not many years are elapsed since we began to make any progress at all in this career; and what has been done is chiefly to be ascribed to the Academy of Sciences at Paris, which proposes annual prizes to the best proficients in the prosecution of this science.

The greatest difficulty arises from the number of powers which act upon the heavenly bodies. If each of these were attracted towards only one single point, there would be very little difficulty in the way; and the great *Newton*, who died in 1728, was the first who gave a complete demonstration of the motion of two bodies which have a mutual attraction, in conformity to the law which I have laid down. In virtue of this law, were the earth attracted towards the sun only, we should be able perfectly, without research, to determine its motion. The same thing would apply to the other planets, Saturn, Jupiter, Mars, Venus, and Mercury, if they were attracted only by the sun. But the earth being attracted, not only by him, but by all the other heavenly bodies, the question becomes infinitely more complex and difficult, from the great diversity of powers to which we must pay attention. You may neglect, however, the powers with which it is attracted towards the fixed stars; because, however enormous their masses may be, they are so prodigiously distant, that the power which they exercise upon the earth may be considered as just nothing.

The motion of the earth, therefore, and of the other planets, will always be as perfectly the same as if the fixed stars did not exist. Excepting, then, the power of the sun, we have only to consider the power with which the planets mutually attract each other. Now, these powers are extremely small, compared to those by which each planet is attracted towards the sun, because the mass of the sun is much greater than that of each planet.

As, however, these powers increase according as the distances diminish, so that a power four times greater corresponds to a distance twice less; and a power nine times less corresponds to a distance three times greater, and so on, according to the squares of the numbers, as I explained the subject in the preceding Letter, it might be possible for two planets to approach so near that their attractive power should become equal to that of the sun, nay, greatly exceed it.

Fortunately, this never takes place in our system, and the planets always remain at such a distance from each other, that their attractive power is ever incomparably smaller than that of the sun. For this reason, without extending our views beyond what is thus certainly known, we may consider every planet as attracted only by the power of the sun, and by that it is easy to determine its motion.

This, however, can take place only when we are disposed to rest satisfied with a result near the truth; for if we wish to have more exact information, we must attend to those feebler powers with which the planets act upon each other—powers which really produce the little irregularities clearly observed by astronomers; and to the attainment of the perfect knowledge of these is directed all the sagacity of both astronomers and geometricians.

15*th September*, 1760.

LETTER LIX.

System of the Universe.

In order the more clearly to elucidate what I have been advancing respecting the motion of the heavenly bodies, and the powers which produce it, permit me to present to you (see *Fig.* 37, *Frontispiece*) the system of the universe, or a description of the heavenly bodies which compose it.

We must, first of all, observe, that the fixed stars are bodies entirely similar to the sun, and luminous of themselves; that they are at a very great distance from that luminary, and also very distant from each other; and that every one of them is, perhaps, of equal magnitude with the sun. You are already informed, that the fixed star nearest to us is at least 400,000 times more distant than the sun. Each of the fixed stars seems designed to communicate light and heat to a certain number of opaque bodies, similar to our earth, and, undoubtedly, inhabited likewise, placed near them, but which we cannot see, on account of their prodigious distance.

Though it is impossible to ascertain this by actual observations, we must conclude it, from their analogy to the sun, who serves to warm and to illuminate the earth and the other planets. We know, particularly six of these bodies; they are not in a state of rest, but each of them moves round the sun, in the direction of a curve line, somewhat different from a circle, and which is called the planet's orbit. The sun himself is nearly in a state of rest, as well as all the fixed stars; the motion which they appear to have being entirely owing to that of the earth.

I have accordingly represented, on the annexed sheet (*Fig.* 37, *Frontispiece*), what is called the Solar System, which contains all the opaque bodies that move round the sun, and derive from him all the benefits which he imparts to us. This sign ☉ represents the *Sun* at rest. You see, besides, the *eleven* circles, representing the orbits described by the planets in their motion round him.

That nearest to the sun is *Mercury*, marked by the sign ☿, and the little circle you see in the orbit represents the body of Mercury, who performs his revolution round the sun in about 88 days.

Next comes *Venus*, marked by ♀, who completes a revolution round the sun in seven months nearly.

The third circle is the orbit of the *Earth*, marked by the sign ⊕, and which completes a revolution round the sun in a year. We have no other meaning, in truth, to the word year, but the time employed by the earth in performing a revolution round the sun; and the duration of the common year nearly approaches to this solar year.

But while the earth is moving round the sun, there is another body moving round the earth, and keeping the direction of its orbit; this is the *Moon*, whose own circle, or orbit, is marked by ☽.

The two first planets, *Mercury* and *Venus*, have no visible bodies which attend them; neither has *Mars* ♂, which is the fourth, and performs his revolution in about two years.

The next circle is the orbit of *Jupiter*, marked by ♃, who performs his revolution in twelve years nearly. Round him move four satellites, represented in the Plate, with their orbits, and marked by the figures 1, 2, 3, 4.

The next circle is the orbit of *Saturn*, marked thus, ♄, who employs almost thirty years in performing one revolution round the sun. This planet is attended in his course by seven satellites, marked by the figures 1, 2, 3, 4, 5, 6, 7. Thus, then, the solar system consists of six (now *eleven*) primary planets, Mercury ☿, Venus ♀, the Earth ♁, Mars ♂, Jupiter ♃, Saturn ♄, and eighteen secondary planets or satellites, namely, the Moon, the four attendants of Jupiter, the seven of Saturn,* and the six of the Georgium Sidus.

This system contains, besides, several comets, the number of which is unknown. The figure on the Plate represents one of them, whose orbit differs from that of the planets, because it is drawn out into extreme length, so that a comet sometimes approaches very near to the sun, and sometimes removes to such an immense distance as entirely to disappear. Of comets it has been remarked, that one finishes his revolutions in his orbit in about sixty years; this is the one that was visible last year.† As to the other comets, it is certain that they employ several centuries in performing one revolution in their orbits; and as, in past ages, no exact observations were made of them, we are totally in the dark with respect to their return. Of these, then, consists the solar system; and, most probably, every fixed star has one similar to it.

17th September, 1760.

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* We have added in the figure the orbits of the new planets, discovered since the time of Euler, viz. *Ceres*, *Pallas*, *Juno*, and *Vesta*, whose orbits are situated between those of Mars and Jupiter; and the *Georgium Sidus*,(1) which is situated beyond the orbit of Saturn. The last of these planets is attended with *six* satellites.—*Ed.*

† A comet has lately been discovered, which performs its revolution within the planetary system in 1204 days.—*Ed.*

(1) Called in the United States, and generally in Europe, after the discoverer,—"*Herschel*;" by some of the French writers, "*Uranus*."—Am. Ed.

LETTER LX.

The same Subject continued.

In addition to what I have said respecting the solar system, I must communicate some observations for the explanation of the figures. And, first, it must be remarked, that the lines which mark the paths in which the planets move have no real existence in the heavens, as the whole immensity of space in which they move is a vacuum, or rather filled with that subtile matter which we call the *ether*, and which I have already so often mentioned.

Again, the orbits of the planets are not all in the same plane, as the figure presents them: but if the orbit which the earth describes round the sun is properly represented on the paper, we must imagine the orbits of the five other planets to be partly elevated, and partly depressed, with reference to it; or that the orbit of each planet bears upon it an oblique direction, making an intersection with the paper, under a certain angle, which it is impossible to represent in a figure drawn upon a plane.

Further, the orbits of the planets are not circles, as the figure appears to indicate, but rather somewhat oval, one more, another less so; no one, however, recedes very considerably from the circular form. The orbit of Venus is almost a perfect circle; but those of the other planets are more or less extended lengthwise, so that these planets are sometimes nearer to the sun, sometimes farther off.

The orbits of *comets* are particularly distinguishable, being greatly extended in length, as represented in the figure. As to the moon, and the satellites of Jupiter and Saturn, their orbits, too, are nearly circular.

Neither must we conceive them as moving in one and the same direction, as they appear on the plane of the paper; for they do not remain in the same place, but are themselves carried round the sun along with the primary planet to which they belong. It is thus we must understand the lines represented in the figure. Imagination must supply what it is impossible, on a plane surface, accurately to exhibit.

You are now enabled to comprehend with ease what the late *Mr. de Fontenelle* meant to display, in his book on the plurality of worlds. The earth, with its inhabitants, is sometimes denominated a world; and every planet, nay, every one of the satellites, has an equal right to the same appellation—it being highly probable that each of these bodies is inhabited as well as the earth.

There are twenty-nine worlds, then, in the solar system alone. And every fixed star being a sun, round which a certain number of planets perform their revolutions, and of which some have, undoubtedly, their satellites, we have an almost infinite number of worlds, similar to our earth, considering that the number of stars perceptible to the unassisted eye exceeds some thousands, and that the telescope discovers to us an incomparably greater number.

If it is meant to comprehend under the name of *world* the sun, with the planets and their satellites, and which derive heat and light from him, we shall have as many worlds as there are fixed stars. But if by the term *world* we understand the earth, with all the heavenly bodies, or all the beings which were created at once, it is clear that there can be but one world, to which we refer every thing that exists. It is in this sense the term *world* is employed in philosophy, particularly in metaphysics; it is in this sense we say that there is but one world, the assemblage of all created beings, past, as well as present and future, whose existence is subject to general laws.

When, therefore, philosophers dispute, whether our world is the best or not, they proceed on the supposition of a plurality of worlds; and some maintain that the one which exists is the best of all those which could have existed. They consider the Deity as an architect, who, intending to create this world, traced several different plans, of which he selected the best, or that in which the greatest perfections were all combined, in the highest degree, and executed it in preference to all the others.

But the great quantity of evil that prevails, and is diffused over the surface of our globe, and which flows from the wickedness of man, suggests an important inquiry, namely, Whether it would have been possible to create a world wholly exempted from these evils?

In my opinion, a distinction must be carefully made between the plans of a world which should contain corporeal substances only, and those of another world, which should contain beings intelligent and free. In the former case, the choice of the best would be involved in very little difficulty; but in the other, where beings intelligent and free constitute the principal part of the world, the determination of what is best is infinitely beyond our capacity; and even the wickedness of free agents may contribute to the perfection of the world in a manner which we are unable to comprehend.

It would appear that philosophers have not been sufficiently attentive to this distinction, however essential it may be. But I am too sensible of my own incapacity to enter any deeper into this difficult question.

19th September, 1760.

LETTER LXI.

Small Irregularities in the Motions of the Planets, caused by their mutual Attraction.

In order to determine the motion of the bodies which compose the solar system, it is necessary to distinguish the primary planets, which are *Mercury*, *Venus*, the *Earth*, *Mars*, *Ceres*, *Pallas*, *Juno*, *Vesta*, *Jupiter*, *Saturn*, and the *Georgium Sidus*, from their satellites, namely, the moon, the *four* satellites of Jupiter, the *seven* of Saturn, and the *six* of the Georgium Sidus.

It has been explained to you, that these eleven planets are principally attracted towards the sun, or that the force with which they are impelled towards him is incomparably greater than the powers which they exert one upon another, because his mass is incomparably greater than that of the planets, and because they never sufficiently approach to each other to render their reciprocal attraction very considerable. Were they attracted only towards the sun, their motion would be sufficiently regular, and easily determined. But the feebler powers of which I have been speaking occasion some slight irregularities in their motion, which astronomers are eager to discover, and which geometricians endeavour to determine on the principles of motion.

An important question is here agitated—namely, *The powers which act upon a body being known, how to find the motion of that body?* Now, upon the principles above laid down, we are acquainted with the powers, to the influence of which every planet is subjected. Thus the motion of the earth is somewhat affected, first, by the attraction of Venus, which sometimes passes very near it; and, secondly, by that of Jupiter, which, on account of the prodigious mass of this planet, becomes considerable, though he be always at a great distance. The mass of Mars is too small to produce any perceptible effect, though he is sometimes very near us; and Saturn, though his mass be the greatest next to that of Jupiter, is too distant.

The moon, though her mass be very small, produces, however, some derangement, from her being very near the earth. The comet which appeared last year was seven times nearer to us than the sun when his distance was smallest; there is a great degree of probability, therefore, that it may have deranged the earth's motion, especially if his mass was considerable—a circumstance with which we are not acquainted. If this comet were as great as the earth, the effect must have been very considerable; but its apparent smallness induces me to believe that its mass is much less than that of the earth, and consequently its effect must have been proportionally less. When we saw this comet, however, it had got to a great distance: at the time when it was nearest it was invisible to us, but it must have appeared very brilliant to our antipodes.

What has been said respecting the derangements occasioned in the earth's motion takes place likewise in the other planets, regard being had to their mass, and to their proximity. As to the moon, and the other secondary planets, the principle of their motion is somewhat different. The moon is so near the earth, that the attraction she feels from hence greatly exceeds that of the sun, though the mass of this luminary be many thousands of times greater than that of the earth. Hence it is that the motion of the moon follows that of the earth, and that she remains, as it were, attached to it, which makes the moon to be considered as a satellite to our planet.

Had the moon been placed much farther from us, and had she been attracted less towards the earth than towards the sun, she would have become a pri-

mary planet, and performed her own revolutions round the sun; but she is 300 times nearer to us than she is to the sun; hence it is evident that he must exercise a much feebler influence upon her than the earth does. The moon being principally attracted by two bodies, the sun and the earth, it is evident that the determination of her motion must be much more difficult than that of the primary planets, which are subject to the attraction of the sun only, excepting the slight derangements which have been mentioned. The motion of the moon has accordingly in all ages greatly embarrassed philosophers; and never have they been able to ascertain, for any future given time, the exact place of the moon in the heavens.*

You perfectly comprehend, that in order to predict an eclipse, whether of the moon or of the sun, we must be able accurately to ascertain the moon's place. Now in calculating eclipses formerly, there was frequently a mistake of an hour or more, the eclipse actually taking place an hour earlier or later than the calculation. Whatever pains the ancient astronomers took to determine the moon's motion, they were always very wide of the truth. It was not till the great *Newton* discovered the real powers which act upon the moon, that we began to approach nearer and nearer to truth, after having surmounted many obstacles which retarded our progress.

I too have employed much time and attention on the subject: and *Mr. Mayer* of Gottingen, pursuing the track which I had opened, has arrived at a degree of precision beyond which it is perhaps impossible to go.† Not much more, then, than ten years have elapsed since we could boast of any thing like accurate knowledge of the moon's motion. Since that time, we are able to calculate eclipses so exactly as not to make the mistake of a single minute; whereas before, there was frequently the difference of eight minutes and more. To analysis, then, we are indebted for this important discovery, the source of unspeakable advantages, not to the astronomer only, but likewise to the geographer and the navigator.

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* So great has been the improvement of astronomical instruments, so extensive the observation of phenomena, and so much more accurate the tables founded upon them, since the time of Euler, the illustrious author could scarcely have anticipated the progress of his favourite science.—*Am. Ed.*

† The average error of Mayer's best tables, with the improvements of

23d September, 1760.

LETTER LXII.

Description of the Flux and Reflux of the Sea.

The attractive power of the heavenly bodies extends, not only to the mass of the earth, but to all the parts of which it is composed. Thus, all the bodies which we see on the surface of the earth are attracted, not only towards the earth itself, from which results their gravity, and the weight of every one in particular, but likewise towards the sun, and towards all the other heavenly bodies; and that more or less, according to the mass of these bodies and their distance.

Now it is evident, that the force with which a body, say a stone, is attracted towards the earth, must be incomparably greater than that with which the same body is attracted towards the sun, the other planets, and the moon, because of their great distance. Such a body, being at a distance from the centre of the earth equal to a radius of this globe, is 60 times farther from the moon. Though, then, the

Mason, was from 1783 to 1788, 30" in longitude, and 14" in latitude; whereas the average error of our present tables, in 1821, is only 4" in longitude, and 4" in latitude,—so rapid and unlooked for has been the progress of astronomy.—*Ed.*

mass of the moon were equal to that of the earth, the attraction towards the moon would be 60 times 60, that is 3600 times less than the attraction towards the earth, or the gravity of the body. But the mass of the moon is about 70 times less than that of the earth; hence the attractive power of the moon becomes still 70 times 3600, that is, 252,000 times less than the gravity of the body.

Again, though the sun be many thousands of times greater than the earth, he is about 24,000 times more distant from us than the centre of the earth; and for this reason the attraction of the sun upon a stone is extremely small compared to its gravity. Hence you see that the gravity of terrestrial bodies, which is nothing else but the force with which they are attracted towards the earth, cannot be perceptibly affected by the attraction of the heavenly bodies.

Though this attraction, however, be very inconsiderable, there results from it a remarkable phenomenon, which long puzzled philosophers; I mean the *tides*, or the flux and the reflux of the sea. It occurs so frequently, even in common conversation, that it is almost a matter of necessity to understand it. For this reason, I propose to explain more minutely this singular phenomenon, and to unfold the causes which produce it.

I begin, then, with the description of the well-known phenomenon of the *flux* and *reflux* of the sea. Hardly any one is ignorant, that by far the greatest part of the surface of our globe is covered with a mass of water, called the *sea*, or the *ocean*. This immense fluid mass is very different from rivers and lakes, which, according to the different seasons of the year, contain sometimes less water, sometimes more, whereas in the sea the quantity of water at all times continues nearly the same. It is, however, observed, that the water of the sea rises and falls alternately with wonderful regularity twice every twenty-four hours.

If, for instance, in a harbour the water is now at its greatest height, it will presently begin to subside; and this decrease continues for six hours, at the end of which its depth will be at the lowest. It then begins again to rise, and the increase likewise lasts six hours, when it is again at its greatest depth. It immediately begins again to fall for six hours, and then rises as many; so that in the space of about twenty-four hours the water rises and falls twice; and arrives alternately at its greatest and least depth.

It is this alternate increase and diminution of the water of the sea which we call its *flux* and *reflux*, or its flowing and ebbing; and more particularly, the flux denotes the time during which it increases or rises, and the reflux the time of its decrease or falling. The flux and reflux together likewise go by the name of *tide*. This alternation, then, is to be the subject of our present disquisition.

It is first of all to be remarked, that the difference between rising and falling keeps pace with the variations of the moon. At full and new moon the water rises higher than at the quarters; and about the time of the vernal and autumnal equinoxes, in the months of March and September, this alternate motion of the sea is most considerable. A great difference is likewise observed, according to the situation of the coasts. The flux in some places is never more than a few feet, while in others the rise is forty feet and upwards. Such are the tides in the ports of *St. Malo* in France, and of *Bristol* in England.*

It is further to be remarked, that this phenomenon is perceptible chiefly in the ocean, where there is a vast extent of water; and that in seas bounded and confined, such as the *Baltic* and the *Mediterranean*, it is much less considerable. The interval from the flux to the succeeding reflux is not exactly six hours, but about eleven minutes more; so that the same changes do not take place the day after at the same hour, but fall out about three-quarters of an hour later: so that a revolution of thirty days is requisite to bring them round to the same hour; now, this is precisely the period of one revolution of the moon, or the interval between one new moon and that which immediately follows.

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* The tide rises on the N.E. coast of America, and especially in the Bay of Fundy, to the height of 60 feet.—*Am. Ed.*

26th September, 1760.

LETTER LXIII.

Different Opinions of Philosopher's respecting the Flux and Reflux of the Sea.

WHEN the water of the sea rises at any place, we are not to imagine that it swells from any internal cause, as milk does when put in a vessel upon the fire. The elevation of the sea is produced by a real increase of water flowing hither from some other place.* It is a real current, which is very perceptible at sea, conveying the waters towards the place where the flux is.

In order to have a clear comprehension of this, you must consider that in the vast extent of the ocean there are always places where the water is low, while it is high at others; and that it is conveyed from the former to the latter. When the water rises at any place, there is always a current, conveying it from other places, where it is of course at that time low. It is an error, therefore, to imagine, with some authors, that during the flux of the sea the total mass of water becomes greater, and that it diminishes during the reflux. The entire mass or bulk of water remains ever the same; but it is subject to a perpetual oscillation, by which the water is alternately transported from certain regions to others; and when the water is high at any place, it is of course low somewhere else, so that the increase at places where it is high is precisely equal to the decrease at those where it is low.

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* That part of the sea only is meant at which the tide rises. An elevation at one place produces of course a depression at another.—*Am. Ed.*

Such are the phenomena of the flux and reflux of the sea, the cause of which ancient philosophers endeavoured to discover, but in vain. *Kepler*, in other respects a great astronomer, and the ornament of Germany, believed that the earth, as well as all the heavenly bodies, was a real living animal, and considered the flux and reflux of the sea as the effect of its respiration. According to this philosopher, men and beasts were just like insects feeding on the back of the huge animal. You will hardly expect I should go into the refutation of an opinion so ridiculous.

Descartes, that great French philosopher, endeavoured to introduce a more rational philosophy; and remarked, that the flux and reflux of the sea was principally regulated by the moon's motion; which was indeed a very important discovery, though the ancients had already suspected a connexion between these two phenomena. For if high water, or the top of the flux, happen to-day at noon, it will be low water at eleven minutes after six in the evening: it will rise till 22 minutes after midnight; and the next low water will be 33 minutes after six in the morning of the day after; and the ensuing high water, or flux, will be three-quarters of an hour after noon: so that from one day to another the same tides are later by three-quarters of an hour.

And as the same thing precisely takes place in the moon's motion, which rises always three-quarters of

an hour later than the preceding day, it was presumable that the tides followed the course of the moon. If at any given place, for example, on the day of new moon, high water happen to be at three of the clock, afternoon, you could rest assured that ever after, on the first day of the moon, the flux would invariably be at the height at three o'clock afternoon, and that every following day it would fall later by three-quarters of an hour.

Again, not only the time when every flux and reflux happen exactly follows the moon, but the strength of the tides, which is variable, appears still to depend on the position of the moon. They are everywhere stronger after the new and full moon, that is, at these periods the elevation of the water is greater than at other times; and after the first and last quarters, the elevation of the water, during the flux, is smaller. This wonderful harmony between the tides and the motion of the moon was, undoubtedly, sufficient ground to conclude, that the chief cause of the flux and reflux of the sea was to be sought for in the action of the moon.

Descartes accordingly believed that the moon, in passing over us, pressed the atmosphere, or the air which surrounds the earth, and that the air, pressing on the water, in its turn forced it to subside. Had this been the case, the water must have been depressed at the places over which the moon was, and the same effect should be produced twelve hours after in the ensuing tide; which, however, does not happen. Besides, the moon is too distant from the earth, and the atmosphere too low, to be impressed by the moon; and admitting that the moon, or any other great body, were to pass along the atmosphere, it would be very far from undergoing any pressure from it, and still less would the sea feel this pretended pressure.

This attempt of *Descartes* to explain the flux and reflux of the sea has therefore failed; but the connexion of this phenomenon with the moon's motion, which this philosopher has so clearly unfolded, enabled his successors to employ the application of their researches with more effect. This shall be the subject of some following Letters.

30th September, 1760.

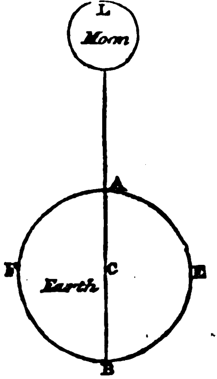
LETTER LXIV.

Explanation of the Flux and Reflux, from the Attractive Power of the Moon.

Descartes's method of explaining the flux and reflux of the sea, by the pressure of the moon upon our atmosphere, not having succeeded, it was reasonable to look for the cause of it in the attraction which the moon exercises upon the earth, and consequently also upon the sea.

The attractive power of the heavenly bodies having been already sufficiently established by so many other phenomena, as I have shown, it could not be doubted that the flux and reflux of the sea must be an effect of it. As soon as it is demonstrated that the moon, as well as the other heavenly bodies, is endowed with the property of attracting all bodies in the direct ratio of their mass, and in the inverse ratio of the square of their distance, it is easily comprehended that its action must extend to the sea; and the more so, as you must frequently have observed that the smallest force is capable of agitating a fluid. All that remains, therefore, is to inquire, whether the attractive power of the moon, such as we suppose it, is capable of producing in the sea the agitation known to us by the name of flux and reflux.

Fig. 34.



Let the annexed figure, *Fig*. 34, represent the earth and the moon. A is the place where we see the moon over the earth; B that which is directly opposite, or the antipodes of A; and C is the centre of the earth. As the point A is nearer the moon than the point B, a body at A is more powerfully attracted towards the moon than a similar body at B. And if we suppose a third similar body to be placed at the centre of the earth C, it is evident that the body A will be more powerfully attracted towards the moon than the body C, and this last than the body B, because the body A is nearer to the moon, and the body B more remote than the body C. But similar bodies placed at E and F are almost as much attracted by the moon as that which is at the centre of the earth C, as they are all three nearly equidistant from the moon.

Hence we see that bodies placed on the surface of the earth are not all equally attracted towards the moon. This inequality of attraction depends on the inequality of their distance from the centre of the moon L, so that a body is so much the more powerfully attracted by the moon as its distance is less; and the contrary takes place according as the distance is greater.

To these differences in the action of the moon on bodies differently situated we must here chiefly pay attention; for if all bodies were equally attracted towards the moon, they would equally obey this power, and no derangement could take place in their mutual situation.

You can easily form the idea of several carriages drawn along by powers perfectly equal; they will proceed on the road, always preserving the same order, and the same distances; but as soon as some of them advance more briskly, and others more slowly, the order will be deranged. The same thing takes place in the case of the different bodies which are attracted by the moon; if they all felt in the same degree the action of that luminary, they would preserve the same relative situation, and we should perceive no change in them: but as soon as the force with which they are attracted towards the moon varies as to each of them, their order and their relative situation necessarily change, unless they are attached to each other by bands which that power is unable to burst asunder.

But this is not the case with the sea, as all the particles of a fluid are easily separated from each other, and every one may obey the impressions which it receives. It is evident, then, that when the powers which act on the different parts of the sea are not equal to one another, an agitation, or derangement, must be the consequence.

We have just seen that the different parts of the sea are attracted unequally by the moon, according as they are unequally distant from her centre; the sea must, therefore, be agitated by the force of the moon, which, continually changing her situation with respect to the earth, and performing a revolution round it in about twenty-four hours and three-quarters, makes the sea undergo the same changes, and presents the same phenomena in the same period of twenty-four hours and three-quarters; the flux and reflux must, therefore, be retarded from one day to another three-quarters of an hour, which is confirmed by constant experience.

It now remains that we show how the alternate

elevation and depression of the sea, which succeed each other after an interval of six hours and eleven minutes, result from the inequality of the powers of the moon. This I propose to examine in my next Letter.

4th October, 1760.

LETTER LXV.

The same Subject continued.

You have seen that the moon causes no alteration in the state of the earth, but in so far as she acts unequally on its different parts. The reason of it is, that if all its parts equally felt the same action, they would be equally attracted, and no change in their relative situation would result from it.

But a body being at A (*Fig.* 34, p. 219), nearer the moon than the centre of the earth C, is more powerfully attracted to it than a body at C would be; it will approach it, then, with greater velocity than this last: from hence it necessarily follows, that the body A retires from the centre C, and approaches the moon; as if there were two chariots, the one at A, the other at C, and if the chariot A were drawn towards L with greater force than the chariot C, it would remove from C. It is thus that the power of the moon has a tendency to withdraw the point A from the centre C.

Now, to remove a body from the centre of the earth is to raise it; and the water at A being now the thing in question, it is certain that the force of the moon tends to raise the water which is at A, by a power equal to the excess of the attraction towards the moon felt at A above that felt at C. By this power, then, the moon raises the waters of the earth which are immediately under her.

Let us now, likewise, attend to a body at B, directly opposite to the point A; the centre of the earth C, more powerfully attracted by the moon than the point B, will approach nearer to it, and this last, so to speak, will remain behind, just as a chariot which is drawn more slowly than that which precedes it. The point B will consequently remove from the centre C, and rise; for to remove from the centre of the earth, and to rise, is one and the same thing.

It is evident, therefore, that the power of the moon tends to raise the waters, not only at A, but likewise at B, the point diametrically opposite, and that by a force equal to the difference of the attraction of the moon at B and at C, which is less at B than at C. Now, those who are at A have the moon directly above them, or in their zenith; and those who are at B see nothing of the moon, because she is then in a point of the heavens diametrically opposite to their zenith, called *nadir*.

Hence it appears, that at whatever part of the sea it may be, the water must rise equally when the moon is in the zenith of that place and in its nadir, or, when the moon is at its greatest elevation above the horizon, or at its greatest depression under it. At the intermediate periods, when the moon is in the horizon, either rising or setting, she exercises no power capable of raising the sea; a small contrary power tends even to make it fall.

According to this system, at the place of the sea where the moon is in the zenith, its power has a tendency to raise the waters; about six hours after, when she has reached the horizon, her power has a tendency to make them fall. Twelve hours and twenty-two minutes after, the moon being then at the point most distant under the horizon, she exercises the same power to raise the water; and at the end of eighteen hours thirty-three minutes, when she has got to the opposite horizon, the waters are fallen; till at length, twenty-four hours and forty-five minutes from the first period, she returns to the zenith, raising the water as on the preceding day; and this is confirmed by uniform experience.

This alternate elevation and depression of the sea at intervals of six hours and eleven minutes, having such a perfect conformity with the moon, leaves us no room to doubt that the flux and reflux of the sea are caused by the attractive power of the moon.

It is a remarkable circumstance that she acts equally on the sea, in raising it, whether she is at her greatest height above the horizon, or at the most distant point under it. This appeared at first very strange to philosophers, who imagined that the moon must produce under the horizon an effect contrary to that which she produces when in the zenith. But you see clearly that the moon produces the same effect in these two diametrically opposite positions; as I have demonstrated in the figure above referred to, that the effect of the moon is the same at A and at B.

7th October, 1760.

LETTER LXVI.

The same Subject continued.

From what has been said respecting the flux and reflux of the sea, you must be sensible that the system of *Newton*, which I have adopted, is directly contrary to that of *Descartes*. According to this last, the moon exercises a pressure, and the sea must subside at places situated directly under her: but, according to *Newton*, she acts by attraction, and forces the water to rise at these very places.

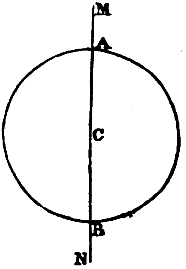
Experience, then, must determine which of these two systems is to be received. No more is necessary than to consult the observations made with respect to the ocean, in order to see whether the water rises or falls when the moon is in the zenith. Recourse has actually been had to this; but it is found that when the moon is at either the zenith or nadir of a given place, the water there is neither high nor low; and that high water does not take place till some hours after the moon has passed the zenith.

From this circumstance, persons who examine things superficially concluded at once that neither of the systems was admissible; and the Cartesians have taken advantage from it, presuming, that if *Newton's* was rejected, that of *Descartes* must necessarily be adopted, though the observations referred to are as contrary to the system of *Descartes* as they appear to be to that of *Newton*.

But the system of *Descartes* is overturned by this single phenomenon, that the sea is always in the same state after a period of twelve hours and twenty-two minutes, or that its state is always the same, whether the moon be above or below the horizon; and it is impossible for its supporters to show how the moon, being over the heads of our antipodes, can produce the same effect as when she is over ours. For this purpose, see *Fig.* 35.

Experience proves that the state of the water at A is the same, whether the moon be at M, the zenith of the point A, or at N, its nadir, which is consequently the zenith of the antipodes at B. The effect of the moon, then, on the water at A, is the same in both cases. But if the moon acted by pressure, according to *Descartes*, it would follow that when the moon is at M, the water at A must fall; and if she were at N, it is impossible that the water at A should undergo the same pressure.

Fig. 35.



In the system of attraction, on the contrary, it is incontestably certain, that the action of the moon must be nearly the same whether that luminary be at M or at N; and this is demonstrated by actual observation.

I must here repeat a preceding explanation, because it is a matter of the utmost importance. When the moon is at M, the point A is nearer it than the centre C; it is therefore more powerfully attracted than the centre; the point A will remove from the centre, consequently it will then rise; the moon, being at M, has a tendency to raise the water at A. Let us now see what effect the moon, being at N, will produce, where she arrives in twelve hours and twenty-two minutes after she was at M. As the point A is more distant from the moon at N than the centre C, it will be more feebly attracted; the centre C will advance with greater velocity towards N than the point A; the distance A C will accordingly become greater; the point A will therefore be more distant from the centre C. But to be more distant from the centre of the earth is to rise, consequently the moon, being at N, makes the point A to ascend, that is, she has a tendency to raise the water at A, as if the moon were at M.

But here experience presents a very formidable objection; for it is observed, that the moon being at M, or at N, the water is not then at its greatest elevation at A. This does not take place till a considerable time after, and thence some have been induced to reject this explanation altogether. But you will easily see that their decision is extremely precipitate.

I have not said, that when the moon is at M or N, the water at A is at its greatest height; I have only said, that the power of the moon has then a tendency to make the water rise. But the water at A could not rise unless its quantity were increased; and that increase can be produced only by the flowing of the water from other parts, some of them very distant. A considerable time, therefore, is requisite to the accumulation of a sufficient quantity of water; it is, then, very natural to suppose that high water at A should not take place for some time after the moon has passed M or N. This observation, therefore, is so far from overturning our system, that it tends strongly to confirm it.

There is no room to doubt that the power which has a tendency to raise the sea must precede its greatest elevation, nay, that a considerable time must intervene, as the water must flow thither from places very remote, that is, from places where the water must be low, while it is high at A. If the water has to pass through straits, or has its current otherwise obstructed, high water will be still more retarded; and if in the ocean it is high water at A two hours after the moon has passed M or N, it will not be at the height in narrow and bounded seas for three hours or more: and this perfectly agrees with daily observation.

11*th October*, 1760.

LETTER LXVII.

The same Subject continued.

It is no longer, then, a matter of doubt, that the flux and reflux of the sea is caused by the attractive power of the moon. But there remains one difficulty more to be removed: Why is the motion of the sea much more considerable at the time of new and full moon than at the quarters? If the moon were nearer the earth when she is new, or full, than when she is in her quarters, there would be no difficulty in the question, as her proximity would increase her power. But though the moon approaches the earth sometimes more, sometimes less, the dif-

ference is always too small to occasion a change so considerable in the flux and reflux of the sea.

Besides, this difference is not regulated by the new and full moon; and it may happen that the moon, in the intermediate quarters, should be nearer to us than when she is new or full. We must have recourse, therefore, to another cause capable of increasing the flux and reflux of the sea at the new and full moon, and of diminishing it at the intermediate quarters.

The system of attraction shows us at first, that it is the action of the sun which, joined to that of the moon, furnishes a complete solution to all the phenomena presented to us by the flux and reflux of the sea. Indeed, all that I have said respecting the power which the moon exercises on the sea is equally applicable to the sun, whose attractive power acts likewise unequally on all the parts of the earth, according as they are more or less remote from him. The attraction of the sun is even much more intense than that of the moon, as it chiefly regulates the motion of the earth, and carries it round its orbit.

As to the motion which he communicates to the sea, it depends on the inequality of that action, with relation to the different points of the surface of the earth, which are more or less attracted towards the sun than its centre—as I have already shown you, in explaining the effect of the moon. If all the parts of the earth were attracted equally, no change in their mutual situation would take place. But though the power of the sun be much greater than that of the moon, the inequality, with relation to different parts of the earth, is nevertheless smaller, on account of the great distance of the sun, which is 400 times farther from us than the moon. The difference of the power with which the centre of the earth, and the points of its surface, are attracted towards the sun, is therefore very small; and from calculations actually made, it is found to be three times less, nearly, than that of the moon upon these points. The attractive power of the sun alone, then, would likewise be capable of causing the flux and reflux of the sea; but it would be about three times less than that which is the effect of the combined influence of these two luminaries.

It is evident, then, that the flux and reflux of the sea are produced by the power of both the sun and the moon, or that there are really two tides occasioned, the one by the moon, the other by the sun, and called the *lunar tide* and the *solar tide*. That of the moon, nearly three times greater, follows its motion, and from one day to another is retarded three-quarters of an hour; that which follows the action of the sun would constantly correspond to the same hours of the day, if it existed alone, or if there were no moon. These two tides, the lunar and the solar, together produce the flux and reflux of the sea: but as the one and the other separately make the waters of the sea alternately to rise and fall, when it happens that these two causes conjointly make the sea rise and fall, its flux and reflux become much more considerable; but when the one tends to raise the sea, and the other to lower it, at the same place, when they act in contrary directions, the one will then be diminished by the other, and the lunar tide will be weakened by the solar. According as these two tides assist or check each other, the flux and reflux will then be more or less considerable.

Now, as at the time of new moon the sun and moon are in the same parts of the heavens, their effects being perfectly in unison, the flux and reflux must then be greatest, being equal to the sum of the two tides. This will equally take place at the time of full moon, when the moon is opposite to the sun, as we know that she produces the same effect, though she be in a point of the heavens diametrically opposite to the first. The flux and reflux must therefore be greater at new and full moon than at the first and last quarters. For then the power of the sun is exerted to lower the waters, and that of the moon to raise them. It is evident, therefore, that at these seasons the flux and reflux must be less considerable: and actual observation confirms it.

It might be still further demonstrated by calculation, that the effect of the moon, or of the sun, is somewhat greater when these bodies are at the equator, or equally distant from the two poles of the globe: which happens at the time of the equinoxes, towards the end of the months of March and September. It is found, too, that at that time the tides are strongest. It follows, beyond all doubt, then, that the tides, or the flux and reflux of the sea, are caused by the attractive power of the moon and of the sun, inasmuch as these powers act unequally on the different parts of the sea. The happy explanation of this phenomenon, which had so dreadfully perplexed the ancients, is a complete confirmation of the system of attraction, or of universal gravitation, on which is founded the motion of all the heavenly bodies.

14th October, 1760.

LETTER LXVIII.

More particular Account of the Dispute respecting Universal Gravitation.

Having given you a general but exact idea of the powers which produce the principal phenomena of the universe, and on which are founded the motions of all the heavenly bodies, it is of importance to consider with more attention those powers which are the principal points of the system of attraction.

It is supposed in this system, that all bodies mutually attract each other in the ratio of their mass, and relatively to their distance, in conformity to a law already explained. The satisfactory manner in which most of the phenomena in nature are accounted for proves that this supposition is founded in truth; and that the attraction which different bodies exercise upon each other may be considered as a most undoubted fact. It now remains that we inquire into the cause of these attractive powers; but this research belongs rather to the province of metaphysics than of mathematics. I dare not therefore flatter myself with the prospect of absolute success in the prosecution of it.

As it is certain that any two bodies whatever are attracted to each other, the question is, What is the cause of this attraction? On this point philosophers are divided. The English maintain that attraction is a property essential to all the bodies in nature, and that these bodies, hurried along by an irresistible propensity, tend mutually to approach, as if they were impelled by feeling.

Other philosophers consider this opinion as absurd, and contrary to the principles of a rational philosophy. They do not deny the fact: they even admit that powers exist which are the causes of the reciprocal tendency of bodies towards each other: but they maintain, that they are foreign to the bodies; that they belong to the ether, or the subtile matter which surrounds them, and that bodies may be put in motion by the ether, just as we see that a body plunged into a fluid receives several impressions from it. Thus, according to the first, the cause of the attraction resides in the bodies themselves, and is essential to their nature; and according to the last, it is out of the bodies, and in the fluid which surrounds them. In this case, the term attraction would be improper; and we must rather say that bodies are impelled towards each other. But as the effect is the same whether two bodies are reciprocally impelled or attracted, the word attraction need not give offence, provided it is not pretended by that term to determine the nature itself of the cause.

To avoid all confusion which might result from this mode of expression, it ought rather to be said that bodies move as if they mutually attracted each other. This would not decide whether the powers which act on bodies reside in the bodies themselves or out of them; and this manner of speaking might thus suit both parties. Let us confine ourselves to the bodies which we meet with on the surface of the earth.

Every one readily admits, that all these would fall downwards, unless they were supported. Now, the question turns on the real cause of this fall. Some say that it is the earth which attracts these bodies, by an inherent power natural to it; others, that it is the ether, or some other subtile or invisible matter, which impels the body downwards: so that the effect is, nevertheless, the same in both cases. This last opinion is most satisfactory to those who are fond of clear principles in philosophy, as they do not see how two bodies at a distance can act upon each other, if there be nothing between them. The others have recourse to the divine Omnipotence, and maintain that God has endowed all bodies with a power of mutual attraction.

Though it be dangerous to venture on a dispute concerning the limits of Divine power, it is nevertheless certain that if attraction were an immediate work of that power, without being founded in the nature of bodies, this would be the same thing as saying that God immediately impels bodies towards each other, and this would amount to a perpetual miracle.

Let us suppose that before the creation of the world God had created only two bodies, at a distance from each other; that nothing absolutely existed out of them, and that they were in a state of rest; would it be possible for the one to approach the other, or that they should have a propensity to approach? How could the one feel the other at a distance? Whence could arise the desire of approaching? These are perplexing questions. But if you suppose that the intermediate space is filled with a subtile matter, we can comprehend at once that this matter may act upon the bodies, by impelling them: the effect would be the same as if they possessed a power of mutual attraction.

Now, as we know that the whole space which separates the heavenly bodies is filled with a subtile matter, called *ether*, it seems more reasonable to ascribe the mutual attraction of bodies to an action which the ether exercises upon them, though its manner of acting may be unknown to us, rather than to have recourse to an unintelligible property.

Ancient philosophers satisfied themselves with explaining the phenomena of nature from qualities which they called *occult*, saying, for example, that opium causes sleep, from an occult quality, which disposes it to procure sleep. This was saying just nothing, or rather was an attempt to conceal ignorance. We ought, therefore, likewise to consider attraction as an occult quality, in as far as it is given for a property essential to bodies. But as the idea of all occult qualities is now banished from philosophy, attraction ought not to be considered in this sense.*

18*th October*, 1760.

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* The reasoning of the learned author in this Letter is obviously very deficient in cogency or point. The quality, or *modus operandi*, of his ether in bringing the two bodies together, appears to be as occult as the quality of attraction. It is difficult to perceive why a circumambient ether should have a greater tendency to bring two bodies together than it has to separate them, or why its effect should be similar to attraction any more than to repulsion.—*Am. Ed.*

LETTER LXIX.

Nature and Essence of Bodies; or Extension, Mobility, and Impenetrability of Body.

The metaphysical disquisition, Whether bodies may be endowed with an internal power of attracting each other, without being impelled by an external force, cannot be terminated till we have examined more particularly the nature of body in general. As this subject is of the last importance, not only in mathematics and physics, but in every branch of philosophy, you must permit me to go into a more particular detail of it.

First, it is asked, What is body? However absurd this question may appear, as no one is ignorant of the difference between what is body and what is not, it is, however, difficult to ascertain the real characters which constitute the nature of bodies. The Cartesians say it consists in extension, and that whatever is extended is a body. They clearly understand that extension has in this case three dimensions, and that a single dimension, or extension in length only, gives only a line; and that two dimensions, length and breadth, form only a surface, which still is not a body. To constitute a body, therefore, we must have three dimensions, and every body must have length, breadth, and depth or thickness; in other words, an extension in three dimensions.

But it is asked, at the same time, if every thing which has extension is a body. This must be the case if the definition of *Descartes* be just. The idea which the vulgar form of spectres contains extension; it is, however, denied that they are bodies. Though this idea be purely imaginary, it serves to prove, however, that something may have extension without being a body. Besides, the idea which we have of space contains, undoubtedly, an extension with three dimensions. It is admitted, nevertheless, that space alone is not a body; it only furnishes the place which bodies occupy and fill.

Let us suppose that all those things which are at present in my apartment, air and every thing, were annihilated by the divine Omnipotence, there would remain still in the apartment the same length, breadth, and height, but without a body in it. Here, then, is the possibility of an extension that shall not be a body. Such a space, without body in it, is called a vacuum; a vacuum, then, is extension without body.

It may likewise be said, according to the vulgar superstition, that a spectre has extension, but that body or corporality is wanting to it. It is clear, then, that extension is not sufficient to constitute a body,—that something more is necessary; hence it follows that the definition of the Cartesians is not exact. But what more is necessary, besides extension, to constitute a body? The answer is, mobility, or the possibility of being put in motion; for, though a body be at rest, whatever may be the causes which preserve it in that state, it would, however, be possible to move it, provided the powers applied to it were sufficient. By this, space is excluded from the class of bodies, as we see that space, which only serves to receive bodies, remains immoveable, whatever motion the bodies that it contain may have.

It is likewise said that, by the help of motion, bodies are transported from one place to another; by which we are given to understand that the places and space remain unchangeable. My apartment, however, with the vacuum which I have above supposed, might undoubtedly be moved, and actually is so, as it follows the motion which carries round the earth itself; here, then, is a vacuum in motion, without being a body. The vulgar superstition, too, be-

stows motion on spectres; and this is sufficient to prove that the power of being moved and extension alone do not constitute the nature of bodies. Something more is wanting; there must be matter to constitute a body, or rather, it is this which distinguishes a real body from simple extension, or from a spectre.

Here, then, we are reduced to explain what is to be understood by the term *matter*, without which extension cannot be body. Now, the signification of these two terms is so much the same, that all body is matter, and all matter is body; so that even now we have made no great progress. We easily discover, however, a general character, inseparable from all matter, and consequently pertaining to all bodies; it is *impenetrability*, the impossibility of being penetrated by other bodies, or the impossibility that two bodies should occupy the same place at once. In truth, impenetrability is what a vacuum wants in order to be a body.

It will perhaps be objected, that the hand may be easily moved through air and through water, which are nevertheless acknowledged bodies; these, then, must be penetrable bodies, and consequently impenetrability is not an inherent character of all bodies. But it is worthy of remark, that when you plunge your hand into water, the particles of the water make way for your hand, and that there is no water in the space which your hand occupies. If the hand could move through the water while that fluid did not make room for it, but remained in the place which the hand occupied, then it would be penetrable; but it is evident this is not the case. Bodies, then, are impenetrable: a body, therefore, always excludes from the place which it occupies every other body; and as soon as a body enters into any place, it is absolutely necessary that the body which occupied it before should leave it. This is the sense which we must affix to the term impenetrability.

21st October, 1760.

LETTER LXX.

Impenetrability of Bodies.

The instance of a spunge will perhaps be produced as an objection to the impenetrability of bodies, which plunged into water appears completely penetrated by it. But the particles of the spunge are very far from being so, in such a manner as that one particle of the water should occupy the same place with one particle of the spunge. We know that spunge is a very porous body; and that before it is put into the water its pores are filled with air; as soon as the water enters into the pores of the spunge the air is expelled, and disengages itself under the form of little bubbles; so that in this case no penetration takes place, neither of the air by the water, nor of the water by the air, as this last always makes its escape from the place into which the water enters.

It is, then, a general and essential property of all bodies to be impenetrable; and consequently the justness of this definition must be admitted, *that a body is an impenetrable extension;* as not only all bodies are extended and impenetrable, but likewise reciprocally, as that which is at the same time extended and impenetrable is beyond contradiction a body. Vacuum is accordingly excluded from the class of bodies; for though it has extension, it wants impenetrability; and wherever we meet with a vacuum, there bodies may be introduced without thrusting any thing out of its place.

We must attempt to remove another difficulty raised against the impenetrability of bodies. There are, say the objectors, bodies which admit of compression into a smaller space: as, for example, wool, and especially air, which it is possible to reduce into a space a thousand times smaller than what it occupies. It appears, then, that the different particles of air are reduced in the same place, and that consequently they mutually penetrate.

There is, however, nothing in this; for the air too is a body or a substance full of empty pores, or filled with that fluid, incomparably more subtile, which we call *ether*. In the first case no penetration will ensue, as the particles of air only approach nearer to each other according as the vacuum is diminished; and in the other case, the ether finds a sufficiency of small passages by which to escape as the particles of the air approach each other, but all the while without any mutual penetration. For this reason it is necessary to employ a greater force when we want to compress the air more; and if the air were compressed to such a degree that its minute particles touched each other, we could not carry the compression farther, because, were it possible, the minute particles of the air must mutually penetrate.

It is, then, a necessary and fundamental law in nature, that no two bodies can penetrate each other, or occupy the same place at once; and it is in conformity to this principle that we must look for the real source of all the motions which we observe in all bodies and of the changes which befall them. As two bodies cannot continue their motion without penetrating each other, it is absolutely necessary that the one should give place to the other. If, then, two bodies are moving in the same line, the one to the left, the other to the right, as it frequently happens at billiards, if each were to continue its motion they must mutually penetrate; but this being impossible, as soon as they come to touch a shock takes place, by which the motion of each body is almost instantly changed; and this shock is produced in nature only to prevent penetration. The motion of each body is precisely changed no further than is necessary to prevent all penetration; and in this consists the real cause of all the changes which happen in the world.

When all these changes are attentively considered, they are found always to take place in order to prevent some penetration, which without these changes must have ensued. At the moment I am writing, I observe that if the paper were penetrable, the pen would pass freely into it without writing; but as the paper sustains the pressure of my pen moistened with ink, it receives from it some particles which form these letters, which could not happen if bodies penetrated each other.

This property of all bodies, known by the term *impenetrability*, is then not only of the last importance relatively to every branch of human knowledge, but we may consider it as the master-spring which nature sets a-going in order to produce all her wonders. It merits, then, an attentive examination, in order that we may be enabled to explain more clearly the nature of bodies, and the principles of every species of movement commonly called *laws of motion.*

25th October, 1760.

LETTER LXXI.

Of the Motion of Bodies, real and apparent.

All bodies are at rest or in motion. However evident this distinction may be, it is almost impossible to judge whether a body is in the one state or in the other. The paper which I see on my table seems to me really at rest; but when I reflect that the whole earth is moving with that astonishing velocity which I explained in a former Letter,* my house, my table, and the paper must absolutely be carried along with the same rapidity. Thus every thing that seems to be at rest has in reality the same motion as the earth.

We must therefore distinguish between two kinds of rest; the one absolute, the other apparent. Absolute rest takes place when a body remains constantly in the same place, not with relation to the earth, but with relation to the universe. If the fixed stars remained always in the same place of the universe, they would be at rest, though they seem to move very rapidly; but as we are not certain of it, we must not pretend to affirm that the fixed stars are in a state of absolute rest.

A body is said to be in a state of apparent rest when it preserves the same situation on the earth. It is likewise to be presumed that these terms, rest and motion, have been introduced into language to mark rather appearances than truth; and in this sense I affirm, without hesitation, that my table is at rest as well as the whole earth; and that the sun and the fixed stars are in motion, and that a very rapid motion, although they are really at rest. We should, therefore, be ascribing strange and purely metaphysical ideas to these expressions, if we understood by them *absolute rest* or *motion;* and it is absurd to employ, as some persons do, passages of the Holy Scriptures to prove that the earth is at rest, and the sun in motion.

Language is formed for general use, and philosophers are under the necessity of forming a particular language for themselves. As we are incapable to judge of absolute rest, it is very natural for us to consider those bodies as at rest which preserve the same situation relatively to the earth, as it is very probable the inhabitants of other planets likewise form their judgment of rest from the same situation relatively to their respective planet.

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* Letter II.

We observe, that navigators consider as at rest the objects which preserve the same situation relatively to their vessel, and that the coasts which they discover appear to them to be in motion; and no one thinks of finding fault with their using the common modes of expression. There is, therefore, a great difference between rest and motion, real or absolute, and between rest and motion apparent, or relative to a body, considered at the time as in a state of rest, though perhaps it may be in motion. The principles or laws of motion refer chiefly to the absolute state of bodies, that is, to their rest or motion, real or absolute. In order to discover these laws, we begin with considering a body singly and abstractedly from all others.

This hypothesis, though it never can take place, is in reality very proper to assist us in distinguishing what is operated by the nature of body itself, from that which other bodies are capable of operating upon it.

Let a body then be alone, and at rest; it may be asked, Will it continue at rest, or will it begin to move? As there is no reason which should incline it to move to one side rather than to another, it is concluded that it would remain always at rest. The same thing must happen, on the supposition of the existence of other bodies, provided they do not act on the body in question; hence results this fundamental law: *When a body is once in a state of rest, and nothing external acts upon it, it will remain always in that state: and if it begin to move, the cause of motion would be out of it, so that there is nothing in the body itself which is capable of putting it in motion.* When, therefore, we see a body which has been at rest begin to move, we may rest assured that this motion has been occasioned by an exterior power, as there is nothing in the body itself capable of putting it in motion; and if it were alone, and cut off from all communication with other bodies, it would remain always at rest.

However well founded this law may be, and however entitled to rank with geometrical truths, there are persons little accustomed to profound investigation who pretend that it is contradicted by experience. They allege the example of a thread to which a stone is appended; the stone is at rest, but falls the moment that the thread is cut. It is certain, say they, that the action by which the thread is cut is not capable of making the stone move; the stone, therefore, must fall by a power which is proper to itself, and internal.

The fact is certain; but it is evident, at the same time, that gravity is the cause of the descent, and not an internal power in the stone.

They say, further, that gravity may be an intrinsic power, attached to the nature of the stone; on which it must be remarked, that gravity is produced either by a subtile matter or by the attraction of the earth. In the first case, it certainly is that subtile matter which causes the descent of the stone; in the second, which appears favourable to our opponents, it can with no propriety be affirmed that the stone descends by an intrinsic power; it is rather the earth which contains the cause of it, and which produces the descent of the stone by its attractive power; for if the earth did not exist, or were deprived of its attractive power, they admit that the stone would not descend.

It is certain, therefore, that the cause of the descent does not reside in the stone itself: the cause then is always extrinsic, whether it be in the subtile matter or in the earth, supposing it to be endowed with an attractive power, as the partisans of attraction pretend. This difficulty being removed, the law which I have laid down subsists in full force—namely, that a body, once at rest, will always remain so, unless it be put in motion by some foreign cause. This law must take place, provided the body has been at rest but a single instant, though it was in motion immediately before; and when once reduced to a state of rest, it will always preserve that state, unless some foreign cause intervene to put it again in motion. This principle being the foundation of all mechanics, it was necessary for me to establish it with all possible precision.

28*th October*, 1760.

LETTER LXXII.

Of Uniform, Accelerated, and Retarded Motion.

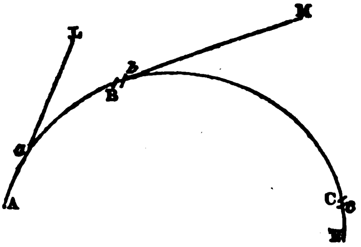
I RETURN to the case of a body placed in such a manner as to have no connexion with any other. Let us suppose it to have received some motion, from whatever cause; it remains that we inquire, What will afterward happen to it? Will it continue to move? or will it suddenly return to a state of rest; or after some time? You must be sensible, that this is an inquiry of some importance, and that all our researches respecting the motion of bodies depend upon it. Let us examine if, by means of reasoning, we are able to resolve it.

A body is at rest as long as it and all its parts remain in the same place; and it is in motion when that body, or some of its parts only, pass from one place to another. Now, there are two things to be considered in motion, the direction and the velocity. The direction is the place towards which the body is carried, and the velocity is the space, greater or less, through which it moves in a certain time. I am persuaded you have already juster ideas of this than I could communicate by the most ample explanation. I remark only, that as long as a body preserves the same direction, it moves in a straight line

—and reciprocally, as long as a body moves in a straight line, it preserves the same direction; but when it moves in a curve, it is continually changing its position.

If a body, then, *Fig.* 36, moves in the curve A B C;

Fig. 36.



when it is at A, its direction is the small line A *a*; when it is at B, its direction is the small line B *b*; and at C, the small line C *c*. Let these small lines be produced; the continuations of which are marked by the straight dotted lines A L, B M, C N; and it will be affirmed, that when the body passes through A, its direction is the straight line A L, because, if the body preserved the same direction which it had at A, it would move in the straight line A L. It is evident, then, that it moves in the curve only in so far as it is continually changing its direction. And when it arrives at B and at C, the direction from which it deviates is expressed by the straight lines B M and C N.

A body preserves the same velocity in its motion as long as it moves through equal spaces in equal times. This motion is called *uniform*. Thus, for example, if a body moves in such a manner as always to proceed ten feet during every second, we call this motion uniform. If another body proceeds twenty feet in a second, its motion too would be uniform, but its velocity would be twice as great as that of the preceding.

From what I have just said of the uniformity of motion, it is easy to comprehend what is not uniform motion; for when the velocity of a body is not equal, its motion is not uniform. When the velocity of a body goes on increasing, its motion is said to be *accelerated;* and when it is continually diminishing, we say it is *retarded.* In this last case, the velocity may come to be retarded to such a degree that the body shall at length come to a state of rest.

Having made these remarks on the velocity and direction of moving bodies, I return to the case of a solitary body, which I suppose to be put in motion by any cause whatever. As soon as it has begun to move, it must have acquired a certain direction, and a certain velocity: and the question is, Will it afterward preserve the same direction and the same velocity; or will it undergo some alteration? We cannot affirm that it will be reduced to a state of rest in an instant, for in this case it could not have had any motion, all motion supposing duration, however short. Now, as long as the motion lasts, it is certain that the direction will remain the same.

In truth, it is impossible to conceive why the body should go out of its road, to one side rather than to another; and as nothing comes to pass without reason, it follows that the body in question will always persevere in the same direction, or that its motion will proceed in a straight line, which is a great step made towards the decision of the question.

It is likewise maintained that the velocity of the body of which I speak cannot change, for in that case it must either increase or diminish: and no reason can be assigned capable of producing this change. Hence it is concluded, that this body will always continue to move with the same velocity, and in the same direction, or that it will proceed continually in the direction of a straight line, without ever deviating from it, and always with equal speed. This motion will be performed, then, always in a straight line, and with an equal velocity, without ever being slackened or retarded; the body, therefore, will never be reduced to a state of rest.

What has been said of a body, which I have supposed solitary, would happen in like manner to our globe, if no other bodies had any influence upon it; for then it would be the same thing as if they did not exist. The question, then, is resolved. A body in motion will always preserve it in the same direction, and with the same velocity, unless some external cause interpose capable of altering its motion. So long, therefore, as a body is not subject to the action of some external cause, it will remain at rest, if it has once been in a state of rest; or will be moved in the direction of a straight line, and always with the same velocity, if it has once been put in motion; and this is the first and principal law of nature, on which the whole science of motion must be founded.

From it we deduce at once this conclusion, that as often as we see a body which was at rest put in motion, or a body moving in a curve line, or whose velocity changes, it is certain that an external cause acts upon it. No change can possibly take place either as to direction or velocity, but what is the operation of a foreign cause.

1*st November*, 1760.

LETTER LXXIII.

Principal Law of Motion and Rest. Disputes of Philosophers on the Subject.

With whatever solidity this principle is established, that every body put in motion continues to move in the same direction, and with the same velocity, unless some exterior cause interpose to derange this motion—it has nevertheless been combated by certain philosophers, who have never made any great progress in the science of motion; while those to whom we are indebted for all the great discoveries which have been made in this science unanimously agree, that all their researches have proceeded entirely on this principle. It is attacked by two sects of philosophers, whose objections I proceed to propose, and shall endeavour to refute.

It is alleged by the one, That all bodies have a propensity to rest, which is their natural state, and that motion is to them a state of violence; so that when a body is put in motion, it has a tendency from its very nature to return to the state of rest; and that it makes every effort to destroy its motion, independently of every external or foreign cause. They allege, in proof, experience so convincing, according to them, that we know of no motion in nature that does not very sensibly betray this reluctance. Do we not see, say they, on the billiard-table, that with whatever force we strike a ball, its motion is quickly slackened, and it soon returns to a state of rest. As soon as the motion of a clock ceases to be kept up by the external force which set it a-going, it stops. It is remarked of all machines in general, that their motion lasts no longer than the external powers by which they are agitated. Hence they conclude, that a body put in motion is so far from preserving it from any thing in its own nature, that, on the contrary, an external force must be employed to keep it up.

You must be sensible, that if this conclusion is just, our principle is completely subverted; as, in virtue of this principle, the ball and the machines in question, once put in motion, must always preserve the same, unless external causes have occasioned some change in it. Thus, in the experiments referred to, had there been no external cause which tended to destroy the motion, we should have been under the necessity of abandoning our principle.

But if we attend to every thing, we shall find so many obstacles opposed to the motion, that we need no longer wonder it should be so speedily extinguished. In fact, it is first the friction on the billiard-table which diminishes the motion of the ball, for it cannot advance without rubbing against the cloth. Again, the air, being a substance, causes likewise a resistance capable of diminishing the motion of bodies. To be convinced of this, you have only to move your hand rapidly through the air. It is evident, then, that in the case of the billiard-table, it is the friction and the resistance of the air which counteract the motion of the ball, and soon reduce it to a state of rest.

Now, these causes are external, and it is easily comprehensible, that but for these obstacles the motion of the ball must have always continued. The same reasoning is applicable to machines of all kinds, in which the friction which acts on the different parts is so considerable, that it is visibly a very sufficient cause of soon reducing the machine to rest.

Having, then, discovered the real causes which produce, in the cases alleged, the extinction of motion, and that these causes are external, and not resident in the moving body, it is evidently false, that bodies have in their nature a propensity to rest. Our principle, therefore, subsists in full force, and even acquires additional strength from the preceding objections. Every body, then, always preserves the motion which it has once received, unless foreign causes interpose to change the direction, or the velocity, or both at once. And thus we have got rid of one phalanx of the adversaries who combat our principle.

The other is more formidable, for they are no less than the celebrated Wolffian philosophers. They do not indeed openly declare against our principle, nay they even express much respect for it; but they advance others which directly oppose it.

They maintain, that all bodies, in virtue of their nature, are making continual efforts to change their state; that is, when they are at rest, they make an effort to move; and, if they are in motion, make continual efforts to change their velocity and direction. They allege nothing in proof of this assertion, except certain crude reasonings, drawn from their system of metaphysics, which I shall hereafter take occasion to lay before you. I only remark, at present, that this opinion is contradicted by the principle which we have so firmly established; and by experience, which is in perfect conformity with it.

In fact, if it be true that a body at rest remains, in virtue of its nature, in that state, it must be undoubtedly false that it should make, in virtue of its nature, continual efforts to change its state. And if it be true that a body in motion preserves, in virtue of its nature, this motion, in the same direction, and with the same velocity, it is impossible that the same body should, in virtue of its nature, be making continual efforts to change its motion.

These philosophers, in attempting to maintain, at the same time, the true principle of motion, and their own absurd opinion, have fallen into self-contradiction, and thereby subverted their own system. It is therefore placed beyond the reach of dispute, that our principle is founded in the very nature of body, and that whatever is contrary to it ought to be banished from sound philosophy: and this same principle enables us to clear it of certain subtilties in which it has been involved.

This principle is commonly expressed in the two following propositions: First, *A body once at rest will remain eternally at rest, unless it be put in motion by some external or foreign cause:* Secondly, *A body once* *in motion will preserve it eternally, in the same direction, and with the same velocity; or will proceed with a uniform motion, in a straight line, unless it is disturbed by some external or foreign cause.* In these two propositions consists the foundation of the whole science of motion called *mechanics.*

4th November, 1760.

LETTER LXXIV.

Of the Inertia of Bodies: Of Powers.

As we say that a body, so long as it is at rest, remains in the same state, so we likewise say of a body in motion, that as long as it moves in the same direction, and with the same velocity, it remains in the same state. To continue in the same state, then, signifies nothing more than to remain at rest, or to preserve the same motion.

This manner of speaking has been introduced for the purpose of expressing more succinctly our grand principle, that every body, in virtue of its nature, preserves itself in the same state till an extraneous cause come to disturb it—that is, to put the body in motion when at rest, or to derange its motion.

It must not be imagined that a body, in order to preserve the same state, must remain in the same place; this, indeed, is the case when the body is at rest; but when it moves with the same velocity, and in the same direction, we say, equally, that it continues in the same state, though it is every instant changing its place. It was necessary to make this remark, to prevent the possibility of confounding change of place with that of state. If it be now asked, Why bodies continue in the same state? the answer must be, that this is in virtue of their peculiar nature.

All bodies, in as far as they are composed of mat-

ter, have the property of remaining in the same state, if they are not drawn out of it by some external cause. This, then, is a property founded on the nature of bodies, by which they endeavour to preserve themselves in *the same state*, whether of rest or motion. This quality, with which all bodies are endowed, and which is essential to them, is called *inertia*, and it enters as necessarily into their constitution as extension and impenetrability—to such a degree, that it would be impossible for a body to exist, divested of this *inertia*.

This term was first introduced into philosophy by those who maintained that all bodies have a propensity to rest. They considered bodies as somewhat resembling indolent persons, who prefer rest to exertion, and ascribed to bodies an aversion to motion, similar to that which sluggards have for labour ; the term *inertia* signifying nearly the same thing as sluggishness. But though the falseness of this opinion has been since detected, and though it is certain that bodies remain equally in their state of motion as in that of rest, yet the term *inertia* has been still retained, to denote in general the property of all bodies to continue in the same state, whether of rest or of motion.

The exact idea of *inertia*, therefore, is a repugnance to every thing that has a tendency to change the state of bodies; for as a body, in virtue of its nature, preserves the same state of motion, or of rest, and cannot be drawn out of it but by external causes, it follows, that in order to a body's changing its state, it must be forced out of it by some external cause; without which it would always continue in the same state. Hence it is that we give to this external cause the name of *power* or *force*. It is a term in common use, though many by whom it is employed have but a very imperfect idea of it.

From what I have just said, you will see that the word *force* signifies every thing that is capable of changing the state of bodies. Thus, when a body which has been at rest is put in motion, it is a force which produces this effect; and when a body in motion changes its direction, or velocity, it is likewise a force which produces this change. Every change of direction, or of velocity, in the motion of a body, requires either an increase or a diminution of force. Such force, therefore, is always out of the body whose state is changed; for we have seen, that a body left to itself preserves always the same state, unless a force from without acts upon it.

Now, the *inertia* by which a body tends to preserve itself in the same state exists in the body itself, and is an essential property of it; when, therefore, an external force changes the state of any body, the *inertia* which would maintain it in the same state opposes itself to the action of that force; and hence we comprehend, that the *inertia* is a quality susceptible of measurement, or that the *inertia* of one body may be greater or less than that of another body.

But bodies are endowed with this *inertia* in as far as they contain matter. It is even by the *inertia*, or the resistance which they oppose to every change of state, that we judge of the quantity of a body; *inertia* of a body, accordingly, is greater in proportion to the quantity of matter which it contains. Hence we conclude, that it requires a greater force to change the state of a great body, than that of a small one; and we go on to conclude, that the great body contains more matter than the small one. It may even be affirmed that this single circumstance, the *inertia*, renders matter sensible to us.

It is evident, then, that the *inertia* is susceptible of measurement, and that is the same with the quantity of matter which a body contains; as we denominate likewise the quantity of matter in a body its mass, the measure of the *inertia* is the same as that of the mass.

To this, then, is reduced our knowledge of bodies in general. First, we know that all bodies have an extension of three dimensions; secondly, that they are impenetrable; and hence results their general property, known by the name of *inertia*, by which they preserve themselves in their state; that is, when a body is at rest, by its *inertia* it remains so; and when it is in motion, it is likewise by its *inertia* that it continues to move with the same velocity, and in the same direction; and this preservation of the same state lasts till some external cause interpose to produce change in it. As often as the state of a body changes, we must never look for the cause of such change in the body itself; it exists always out of the body, and this is the just idea which we must form of a power or force.

8th November, 1760.

LETTER LXXV.

Changes which may take place in the State of Bodies.

The fundamental principle of mechanics, with the idea of *inertia* which I have endeavoured to explain, enables us to reason on solid ground respecting various phenomena presented to us in nature. On seeing a body in motion, which should proceed uniformly in a straight line, that is, which should preserve the same direction, and the same velocity, we would say, that the cause of this continuation of motion is not to be found out of the body, but that it is founded in its very nature, and that, in virtue of its *inertia*, it remains always in the same state; as we would say, were the body at rest, that this took place in virtue of its *inertia*.

We would likewise be right in saying that this body undergoes no action from any external cause; or, if any such existed, that these powers recipro-

cally destroyed each other in such a manner that the body is in the state in which it would be if no force acted upon it.

If it is asked, then, Why the body continues to move in this manner? the answer is obvious. But if it is asked, Why this body has begun thus to move? the question is totally different. It must be said, that this motion has been impressed upon it by some external force, if it was before at rest; but it would be impossible to affirm any thing with certainty respecting the quantity of that force, because, perhaps, no traces of it remain. It is therefore abundantly ridiculous to ask, Who impressed motion on every body at the beginning of the world? or, Who was the prime mover? Those who put the question admit, then, a beginning, and consequently a creation; but they imagine that God created all bodies at rest. Now, it may be answered, That he who could create bodies could impress motion upon them. I ask them in my turn, If they believe it to be more easy to create a body at rest than in motion? They both equally require the omnipotence of God; and this question belongs not to the province of philosophy.

But when a body has once received motion, it preserves that motion by its own nature, or by its *inertia*, in the same state in which it must constantly remain, until a force, or some foreign cause, oppose an obstacle to it. As often, then, as we observe that a body does not remain in the same state, that a body at rest begins to move, or that a body in motion changes its direction or velocity, we must admit that this change has its cause out of the body, and that it is occasioned by a foreign force. Thus, as a stone left to itself descends, the cause of that descent is foreign to the body; and it is not from its own nature that the body descends, but from the effect of a foreign cause, to which we give the name of *gravity*.

Gravity, then, is not an intrinsic property of body; it is rather the effect of a foreign force, the source of which must be sought for out of the body.* This is geometrically true, though we know not the foreign forces which occasion gravity. It is the same when we throw a stone. We see clearly that it does not follow in its motion the direction of a straight line, and that its velocity does not always continue the same. It is gravity, likewise, which changes the direction of the velocity of the body; but for it, the stone would describe a straight line in the air, and proceed forward with the same velocity; and were gravity to be suddenly annihilated during the motion of the stone, it would continue to move in a straight line, and would preserve the same direction, and the same velocity which it had at the instant when gravity ceased to act upon it.

But as gravity acts continually, and upon all bodies, we need not be surprised that we meet with no motion in which the direction and the velocity continue the same. The case of rest may very well take place; it is when something invincibly opposes the fall of a body; thus, the floor of my apartment prevents my falling into that below it. But the bodies which appear to us at rest are carried along by the motion of the earth, which is neither rectilinear nor uniform: it cannot be affirmed, therefore, that these bodies remain in the same state. Neither is there

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* This assertion is without proof or evidence, unless the author means to imply, that by seeking for the source of gravity out of the body, we shall find it in the will of the Creator. The Newtonian theory of gravity is now universally admitted, except perchance by a few sciolists in philosophy. We can, as Sir Isaac Newton admits, readily conceive of the existence of matter which should not be endowed with the quality of attraction; but as far as human observation has extended, we are justified in ascribing to matter universally this remarkable property. A stone in falling moves therefore by virtue of this property, which it possesses in common with the earth. The attraction and the motion are mutual, but the distance moved through to effect a junction is inversely proportionate to the masses in the moving bodies. Hence the stone appears to move, and not the earth.—*Am. Ed.*

one of the heavenly bodies which moves in a straight line, and always with the same velocity; they are continually changing their state: and even the forces which produce this continual change are not unknown to us; they are the attractive powers which the heavenly bodies exercise over one another.

I have already remarked that these forces may very probably be caused by the subtile matter which surrounds all the heavenly bodies, and fills the whole space of the heavens; but, according to the opinion of those who consider attraction as a power inherent in matter, this force is always foreign to the body on which it acts. Thus, when we say the earth is attracted towards the sun, it is acknowledged that the force which acts upon the earth is not resident in the earth itself, but in the sun; as, in fact, if the sun did not exist there would be no such force.*

This opinion, however, that attraction is essential to all matter, is subject to so many other inconveniences, that it is hardly possible to allow it a place in a rational philosophy. It is certainly much safer to proceed on the idea, that what is called attraction is a power contained in the subtile matter which fills the whole space of the heavens; though we cannot tell how.† We must accustom ourselves to acknowledge our ignorance on a variety of other important subjects.

11th November, 1760.

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* It seems difficult to reconcile this assertion with the opinion that the author understood the Newtonian theory of gravitation. The force exists in the earth as well as in the sun; therefore, in each being directly proportionate to their respective quantities of matter.—*Am. Ed.*

† The Cartesian doctrine, here so distinctly preferred, is now exploded. —*Am. Ed.*

LETTER LXXVI.

System of the Monads of Wolff.

Before I attempt to make you sensible of the truth of the principle, that all bodies of themselves always preserve the same state of rest or motion, I must remark, that if we consult experience only on the subject, without thoroughly investigating it by the powers of reasoning, we would be disposed to draw the directly opposite conclusion, and to maintain, that bodies always have a propensity to be continually changing their state; as we see nothing in the whole universe but a perpetual change in the state of bodies. But we have just shown what are the causes which produce these changes, and we are assured, that they are not to be found in the bodies whose state is changed, but out of them.

The principle, then, which we have established is so far from being contradicted by experience, that it is, on the contrary, confirmed by it. You will easily judge from this, how several great philosophers, misled by an experience not accurately understood, have fallen into the error of maintaining that all bodies are endowed with powers disposing them continually to change their state.

It is thus that Wolff has reasoned. He says, 1. Experience shows us all bodies perpetually changing their state; 2. Whatever is capable of changing the state of bodies is called force; 3. All bodies, therefore, are endowed with a force capable of changing their state; 4. Every body, therefore, is making a continual effort to change; 5. Now, this force belongs to body only so far as it contains matter; 6. It is therefore a property of matter to be continually changing its own state; 7. Matter is a compound of a multitude of parts, denominated the elements of matter; therefore, 8. As the compound can hav nothing but what is founded in the nature of it elements, every elementary part must be endowe with the power of changing its own state.

These elements are simple beings; for if they were composed of parts, they would be no longer elements, but their parts would be so. Now, a simple being is likewise denominated *monad*; every monad, therefore, has the power of continually changing its state. Such is the foundation of the system of monads, which you may have heard mentioned, though it does not now make such a noise as it formerly did. I have marked by figures the several propositions on which it is established, for the purpose of making a more distinct reference, in the reflections I mean to make upon them.

I have nothing to say respecting the first and second; but the third is very equivocal, and altogether false, in the sense in which it is taken. Without meaning to say that the forces which change the state of bodies proceed from some spirit, I readily agree that the force by which the state of every body is changed subsists in body, but it being always understood that it subsists in another body, and never in that which undergoes the change of state; which has rather the contrary quality, that of persevering in the same state. In so far, then, as these forces subsist in bodies, it ought to be said that these bodies, as long as they have certain connexions with each other, may be capable of supplying forces by which the state of another body is changed. It follows, that the fourth proposition must be absolutely false; and the result, from all that went before, rather is, that every body is endowed with the power of remaining in the same state, which is directly the opposite of the conclusion which these philosophers have drawn.

And I must here remark, that it is rather absurd to give the name of *force* to that quality of bodies by which they remain in their state; for if we are to understand by the term *force* every thing that is capable of changing the state of bodies, the quality by which they persevere in their state is rather the opposite of a force. It is therefore by an abuse of language that certain authors give the name of force to the *inertia*, which is that quality, and which they denominate the *inert force.*

But, not to wrangle about terms, though this abuse may lead to very gross errors, I return to the system of monads; and as proposition 4 is false, those that follow, which are successively founded upon it, must of necessity be so too. It is false then, likewise, that the elements of matter, or monads, if such there be, are possessed of the power of changing their state. The truth is rather to be founded on the opposite quality, that of persevering in the same state: and thereby the whole system of monads is completely subverted.

These philosophers attempted to reduce the elements of matter to the class of *beings* which comprehends spirits and souls, endowed, beyond the power of contradiction, with the faculty of changing their state; for, while I am writing, my soul continually represents other objects to itself, and these changes depend entirely on my will: I am thoroughly convinced of it, and not the less so that I am master of my own thoughts; whereas the changes which take place in bodies are the effect of an extraneous force.

Add to this, the infinite difference between the state of body capable only of one velocity and of one direction, and the thoughts of spirit, and you will be entirely convinced of the falsehood of the sentiments of the materialists, who pretend that spirit is only a modification of matter. These gentlemen have no knowledge of the real nature of bodies.

15th November, 1760.

LETTER LXXVII.

Origin and Nature of Powers.

It is undoubtedly very surprising, that if every body has a natural disposition to preserve itself in the same state, and even to oppose all change, all the bodies in the universe should nevertheless be continually changing their state. We are well assured, that this change can be produced only by a force not resident in the body whose state is changed. Where, then, must we look for those powers which produce the incessant changes that take place in all the bodies of the universe; and which are, nevertheless, foreign to body?

Must we then suppose, besides these existing bodies, particular beings which contain those powers? or, are the powers themselves particular substances existing in the world? We know but of two kinds of beings in it, the one which comprehends all bodies, and the other all intellectual beings, namely, the spirits and souls of men, and those of animals. Must we establish, then, in the world, besides body and spirits, a third species of beings, under the name of power or force? or are they spirits which incessantly change the state of bodies?

Both of these labour under too many difficulties to be hastily adopted. Though it cannot be denied that the souls of men and of beasts have the power of producing changes in their bodies, it were, however, absurd to maintain that the motion of a ball on the billiard-table was retarded and destroyed by some spirit; or that gravity was produced by a spirit continually pressing bodies downward; and that the heavenly bodies, which, in their motion, change both direction and velocity, were subjected to the action of spirits, according to the system of certain ancient philosophers, who assigned to each of the heavenly bodies a spirit, or angel, who directed its course.

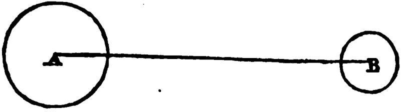
Now, on reasoning with solidity respecting the phenomena of the universe, it must be admitted that if we except animated bodies, that is, those of men and beasts, every change of state which befalls other bodies is produced by merely corporeal causes, in which spirits have no share. The whole question, then, is reduced to this, Whether the forces which change the state of bodies exist separately, and constitute a particular species of beings, or whether they exist in the bodies?

This last opinion appears at first sight very unaccountable; for if all bodies have the power of preserving themselves in the same state, how can it be possible they should contain powers that have a tendency to change it? You will not be surprised to hear that the origin of force has, in all ages, been a stumbling-block to philosophers. They have all considered it as the greatest mystery in nature, and as likely to remain for ever impenetrable. I hope, however, I shall be able to present you with a solution of this pretended mystery, so clear that all the difficulties which have hitherto appeared insurmountable will wholly vanish.

I say, then, that however strange it may appear, this faculty of bodies, by which they are disposed to preserve themselves in the same state, is capable of supplying powers which may change that of others. I do not say that a body ever changes its own state, but that it may become capable of changing that of another. In order to enable you to get to the bottom of this mystery respecting the origin of force, it will be sufficient to consider two bodies, as if no others existed.

Let the body A, *Fig.* 33, be at rest, and let the body B have received a motion in the direction B A,

Fig. 33.



with a certain velocity. This being laid down, the body A is disposed to continue always at rest; and the body B to continue its motion along the straight line B A, always with the same velocity, and both the one and the other in virtue of its *inertia*. The body B will at length then come to touch the body A. What will be the consequence? As long as the body A remains at rest, the body B could not continue its motion without passing through the body A, that is, without penetrating it; it is impossible, then, that each body should preserve itself in its state, without the one's penetrating the other. But this penetration is impossible; impenetrability being a property common to all bodies.

It being impossible, then, that both the one and the other should preserve its state, the body A must absolutely begin to move, to make way for the body B, that it may continue its motion; or, that the body B, having come close to the body A, must have its motion destroyed; or, the state of both must be changed, as much as is necessary to put them in a condition to continue afterward each in his proper state, without mutual penetration.

Either the one body, therefore, or the other, or both, must absolutely undergo a change of their state, and the cause of this change infallibly exists in the impenetrability of the bodies themselves;

since every cause capable of changing the state of bodies is denominated *force*, it is then, of necessity, the impenetrability of the bodies themselves which produces the force by which this change is effected.

In fact, as impenetrability implies the impossibility that bodies should mutually penetrate, each of them opposes itself to all penetration, even in the minutest parts; and to oppose itself to penetration is nothing else but to exert the force necessary to prevent it. As often, then, as two or more bodies cannot preserve themselves in their state without mutual penetration, their impenetrability always exerts the force necessary to change it, as far as is requisite, to prevent the slightest degree of penetration.

The impenetrability of bodies, therefore, contains the real origin of the forces, which are continually changing their state in this world; and this is the true solution of the great mystery which has perplexed philosophers so grievously.

18*th November*, 1760.

LETTER LXXVIII.

The same Subject. Principle of the least possible Action.

You have now made very considerable progress in the knowledge of nature, from the explanation of the real origin of the powers capable of changing the state of bodies; and you are at present in a condition to comprehend easily why all those of this world are subject to an incessant change of state, from rest to motion, or from motion to rest.

First, we are certain that the world is filled with matter. Here below, it is evident that the space

which separates the gross bodies sensible to feeling, is occupied by the air, and that when we make a vacuum in any space the ether instantly succeeds, and it likewise fills the space in which the heavenly bodies move. All space being thus full, it is impossible that a body in motion should continue it a single instant without meeting others, through which it must pass if they were not impenetrable. And as this impenetrability of bodies exerts always and universally a force which prevents all penetration, it is not at all surprising, then, that we should observe perpetual changes in the state of bodies, though every one has a tendency to preserve itself in the same state.

If they could penetrate each other freely, nothing would prevent any one from remaining perseveringly in its state; but being impenetrable, there must thence necessarily result force sufficient to prevent all penetration; and no more results than what is precisely needful.

While they can continue in the same state, without any injury to impenetrability, they then exert no force, and bodies remain in their state; it is only to prevent penetration that impenetrability becomes active, and supplies a force sufficient to oppose it. When, therefore, a small force suffices to prevent penetration, impenetrability exerts that and no more; but when a great force is necessary for this purpose, impenetrability is ever in a condition to supply it.

Thus, though impenetrability supplies these powers, it is impossible to say that it is endowed with a determinate force; it is rather in a condition to supply all kinds of force, great or small, according to circumstances; it is even an inexhaustible source of them. As long as bodies are endowed with impenetrability, this is a source which cannot be dried up; this force absolutely must be exerted, or bodies must mutually penetrate, which is contrary to nature.

It ought likewise to be remarked, that this force is never the effect of the impenetrability of a single body; it results always from that of all bodies at once, for if one of the bodies was penetrable, the penetration would take place, without any need of a power to effect a change in their state. When, therefore, two bodies come into contact, and when they cannot continue in their state without penetrating each other, the impenetrability of both acts equally: and it is by their joint operation that the force necessary to prevent the penetration is supplied, we then say that they act upon each other, and that the force resulting from their impenetrability produces this effect. This force acts upon both of them; for as they have a tendency towards mutual penetration, it repels both the one and the other, and thus prevents their penetration.

It is certain, then, that bodies may act upon each other; and we speak so frequently of this action, as when two billiard balls clash, it is said the one acts upon the other, that you must be well acquainted with this mode of expression. But it must be carefully remarked, that, in general, bodies do not act upon each other, but in so far as their state becomes contrary to impenetrability; from whence results a force capable of changing it, precisely so much as is necessary to prevent any penetration; so that a small force would not have been sufficient to produce this effect.

It is very true, that a greater force would likewise prevent the penetration; but when the change produced in the state of bodies is sufficient to prevent mutual penetration, the impenetrability acts no farther, and there results from it the least force that is capable of preventing the penetration. Since, then, the force is the smallest, the effect which it produces, that is, the change of state which it operates, in order to prevent penetration, will be proportional; and, consequently, when two or more bodies come into contact, so that no one could continue in its state without penetrating the others, a mutual action must take place, which is always the smallest that was capable of preventing penetration.

You will find here, therefore, beyond all expectation, the foundation of the system of the late *Mr. de Maupertuis*, so much cried up by some, and so violently attacked by others. His principle is, that of the least possible action; by which he means, that in all the changes which happen in nature, the cause which produces them is the least that can be.

From the manner in which I have endeavoured to unfold this principle to you, it is evident that it is perfectly founded in the very nature of body, and that those who deny it are much in the wrong, though still less than those who would turn it into ridicule. You will already, perhaps, have remarked, that certain persons, no great friends to *Mr. de Maupertuis*, take every opportunity of laughing at the principle of *the least possible action*, as well as at the hole continued down to the centre of the earth; but fortunately, truth suffers nothing by their pleasantry.

22*d November*, 1760.

LETTER LXXIX.

On the Question, Are there any other Species of Powers?

The origin of powers, founded on the impenetrability of bodies, which I have been endeavouring to explain, is by no means inconsistent with the opinion of those who maintain that the souls of men and those of beasts have the power of acting on their bodies. There is nothing to hinder the existence of two kinds of power, which produce all the changes that take place in the world; the one corporeal, which derives its origin from the impenetrability of bodies; and the other spiritual, which the souls of animals exercise over their bodies: but this last power operates only upon animated bodies; and the Creator has so clearly distinguished it from the other, that it is not permitted, in philosophy, to confound them.

But this distinction greatly embarrasses those who consider attraction as an inherent quality of bodies; for if they act upon each other only to maintain their impenetrability, attraction cannot be referred to this case. Two distant bodies may preserve each its state without at all interesting their impenetrability, and without there being any reason of consequence why the one should act upon the other, even by attracting it.

Attraction, therefore, ought to be referred to a third species of power, which should neither be corporeal nor spiritual. But it is always contrary to the rules of a rational philosophy, to introduce a new species of powers before their existence is incontestably demonstrated. It would have been necessary, therefore, for this effect, to have proved beyond contradiction that the powers by which bodies mutually attract could not derive their origin from the subtile matter which surrounds them; but this impossibility is not yet demonstrated. It would appear, on the contrary, that the Creator has expressly filled the whole space of the heavens with a subtile matter, to give birth to these powers which impel bodies towards each other, conformably to the law before established respecting their impenetrability.

In fact, the subtile matter might very well have a motion, such as that a body in it should not be able to preserve its state without being penetrated by it; and then this force must be derived as well from the impenetrability of the subtile matter as from that of the body itself.

Were there a single case in the world in which two bodies attracted each other, while the interme-

diate space was not filled with a subtile matter, the reality of attraction might very well be admitted; but as no such case exists, we have consequently reason to doubt, nay, even to reject it. We know, then, but of two sources of all the powers which produce these changes, the impenetrability of body, and the action of spirit.

The disciples of *Wolff* reject likewise this law, and maintain, that no spirit, or immaterial substance, can act upon a body; and they are very much embarrassed when it is alleged, that, according to them, God himself, who is a spirit, could not have the power of acting upon bodies, which savours strongly of atheism. They are accordingly reduced to this feeble reply, that it is by *infinity* God is able to act upon body; but if it be impossible for a spirit as a spirit to act upon a body, this impotence necessarily recoils on God himself. And who can deny that our soul acts upon our body? I am to such a degree master of my members, that I can put them in action as I please. The same thing may be affirmed likewise of the brute creation; and as, according to the system of *Descartes*, at which we have good reason to smile, beasts are mere machines, without any feeling, like a watch, as the Wolffians would have it, men too are merely machines.

These same philosophers, in their speculations, go likewise so far as to deny the first species of powers, of which they know nothing. For not being able to comprehend how one body acts upon another, they boldly deny its action; and maintain that all the changes which befall a body are produced by its own powers.

They are the philosophers whom I formerly mentioned, as denying the first principle of mechanics, respecting the preservation of the same state, which is sufficient to subvert their whole system. The error into which they have fallen, as I have already remarked, arises from their reasoning inconclusively respecting the phenomena which bodies present to us. They concluded precipitately, from observing almost all bodies continually changing their state, that they contained in themselves the powers by which they incessantly exert themselves to change it, whereas they ought to have drawn the directly opposite conclusion.

It is thus that, by considering objects in a superficial manner, we hurry into the grossest errors. I have already pointed out the defects of this reasoning; but once fallen into error, they have abandoned themselves to the most absurd ideas. They first ascribed these internal powers to the primary elements of matter, which, according to them, are continual efforts to change their state; and concluded from it, that all the changes to which every element is subjected are produced by its own power, and that two elements, or simple beings, cannot act upon each other. This being laid down, it was necessary to divest spirits, as simple beings, of all power of acting upon body, excepting, however, the Supreme Being; and then, as bodies are composed of simple beings, they were under the necessity of denying also that bodies could act upon each other.

It was in vain to object to them the case of bodies which impinge against one another, and the change of their state which results from it. Obstinately prepossessed in favour of the solidity of their reasoning, they scorned to abandon it: they chose rather to affirm, that every body, from its own nature, produces the change which befalls it, and that the collision has nothing to do with it; that it is a mere illusion which makes us believe the collision to be the cause of it; and they go off in triumph at the sublimity of a philosophy so far beyond the comprehension of the vulgar. You are now in a condition to estimate it according to its real importance.

25th November, 1760.

LETTER LXXX.

Of the Nature of Spirits.

I FLATTER myself that you are now convinced of the solidity of the reasonings on which I have established the knowledge of bodies, and that of the powers which change the state of them. The whole is founded on experiments the most decisive, and on principles dictated by reason. They involve no absurdity, nor are they contradicted by other principles equally certain. It is not long since any successful progress was made in researches of this kind. Such strange ideas were formerly entertained respecting the nature of bodies, that all kinds of powers were ascribed to them, of which some must necessarily destroy the others.

Certain philosophers have even gone so far as to imagine that matter itself might be endowed with the faculty of thought. These gentlemen, known by the name of *materialists*, maintain that our souls, and all spirits in general, are material; or rather, they deny the existence of souls and spirits. But when once we have got into the right road to the knowledge of bodies—the *inertia*, by virtue of which they continue in their state—and *impenetrability*, that quality by which they are subjected to powers capable of changing it—all those phantoms of powers to which I alluded vanish away, and nothing appears a more glaring absurdity than to affirm that matter is capable of thought. To think, to judge, to reason, to possess mental feeling, to reflect, and will, are qualities incompatible with the nature of bodies; and beings invested with them must be of a different nature. Such are souls and spirits; and He who possesses those qualities in the highest degree is GOD.

There is, then, an infinite difference between body and spirit. Extension, *inertia*, and impenetrability—qualities which exclude all thought—are the properties of body; but spirit is endowed with the faculty of thinking, of judging, of reasoning, of feeling, of reflecting, of willing, or of determining in favour of one object preferably to another. There is here neither extension, nor *inertia*, nor impenetrability; these material qualities are infinitely remote from spirit.

It is asked, What is spirit? I acknowledge my ignorance in respect of this; and I reply, That we cannot tell what it is, as we know nothing of the nature of spirit.

But it is not the less certain that this world contains two kinds of beings; beings *corporeal* or *material*, and beings *immaterial* or *spiritual*, which are of a nature entirely different, as they manifest themselves to us by properties which have no relation to each other. These two species of beings are, nevertheless, most intimately united; and upon their union principally depend all the wonders of the world, which are the delight of intelligent beings, and lead them to glorify their CREATOR.

It is certain that spirits constitute the principal part of the world, and that bodies are introduced into it merely to serve them. For this reason it is that the souls of animals are in a union so intimate with their bodies. Not only do the souls perceive all the impressions made upon their bodies; but they have the power of acting upon these bodies, and of producing in them corresponding changes; and thus they exercise an active influence over the rest of the world.

This union of the soul with the body undoubtedly is, and ever will be, the greatest mystery of the divine Omnipotence—a mystery which we shall never be able to unfold. We are perfectly sensible that the human soul cannot act immediately on all

the parts of the body; as soon as a certain nerve is cut, I can no longer close my hand: from which it may be concluded, that the soul has power only over the extremities of the nerves, which all terminate and unite in a portion of the brain, the place of which the most skilful anatomist is unable exactly to assign. To this, then, the power of the soul is restricted. But that of God, being unlimited, extends to the whole universe, and exerts itself by means which far exceed our comprehension.

19*th November*, 1760.

LETTER LXXXI.

Of the Union between the Soul and the Body.

As spirits and bodies are beings, or substances, of a nature totally different, the world contains, then, two kinds of substances, the one *spiritual*, and the other *corporeal* or *material*. The strict union which subsists between them merits a very particular attention.

This union of soul and body, in every animal, is a most wonderful phenomenon. It is reduced to two things—the one, that the soul feels, or perceives, all the changes which befall its body, by means of the senses, which, as you know perfectly well, are five in number, namely, seeing, hearing, smelling, tasting, and touching. By these, then, the soul takes cognizance of every thing that passes, not only in its own body, but out of it. Touching and tasting represent to it those objects only which are in immediate contact with the body; smelling, objects at a small distance; hearing extends to distances much more remote; and sight procures for us the knowledge of the most distant objects.

All this knowledge is acquired only in so far as the objects make an impression on some one of our senses; but still this is not sufficient—it is necessary that the organ of such sense should be perfectly sound, and the nerves belonging to it must not be deranged. You will recollect, that in order to see, the objects must be painted distinctly in the bottom of the eye, on the retina; but still this representation is not the object of the soul; one may be blind, though it is perfectly well defined. The retina is a contexture of nerves, the continuation of which extends to the brain; and if this continuation is interrupted by any injury done to this nerve, called the *optic nerve*, there will be no sight, however perfect the representation on the retina may be.

It is the same with respect to the other senses, all of which operate by means of nerves destined to convey the impression made on the organ employed in the sensation, up to its first origin in the brain. There is, then, in the brain, a certain place where all the nerves terminate; there the soul resides, and there it perceives the impressions made upon it by means of the senses.

From these impressions, the soul derives all the knowledge it has of things out of itself; thence it derives its first ideas, and by their combination forms judgments, reflections, reasonings, and every thing necessary to perfect its knowledge; such is the work of the soul, in which the body has no share. But the first impression comes to it from the senses, through the bodily organs; and the first faculty of the soul is to perceive, or to feel, what passes in that part of the brain in which all the sensitive nerves terminate. This faculty is denominated *feeling*, or *sensation*; and the soul, nearly passive, does nothing, in the first instance, but receive the impressions which body presents to it.

But it possesses in its turn an active faculty, by means of which it has the power of influencing its body, and of producing motions in it at pleasure; in this consists its power over the body. Thus I am

able to move my hands and my feet by an act of my will; and, What motions are my fingers making as I write this letter? My soul, however, cannot act immediately on any one of my fingers: in order to put a single one in motion, it is necessary that several muscles should be put in action; and this action again exerts itself by means of nerves terminating in the brain—if such a nerve be injured, to no purpose will I wish my finger to move; it will no longer obey the orders of my soul. Thus the power of my soul extends only to a small portion of the brain, where all the nerves unite; sensation is likewise restricted to this place of the brain.

The soul, then, is united only with these extremities of the nerves, on which it has not only the power of acting, but by means of which it can view, as in a mirror, every thing that makes an impression on the organs of its body. What wonderful address, to be able to conclude, from the slight changes which take place in the extremity of the nerves, that which occasioned them out of the body!

A tree, for example, produces on the retina, by its rays, an image which is perfectly similar to it; but how feeble must the impression be which the nerves receive from it! It is this impression, however, continued along the nerves up to their origin, which excites in the soul the idea of that tree. Afterward, the slightest impressions which the soul makes on the extremities of the nerves are instantly communicated to the muscles, which, put in action, oblige the member which it wills to move, exactly to obey its orders.

Machines which receive certain motions by the drawing of a string present but a coarse mechanism compared to our bodies and the bodies of animals. The works of the Creator infinitely surpass the productions of human skill.

2d December, 1760.

LETTER LXXXII.

Different Systems relative to this Subject.

In order to elucidate the twofold union of soul and body, we may compare the soul to a man who contemplates, in a dark room, the external objects, and from their images derives the knowledge of what is passing out of the room. The soul viewing, in like manner, if I may so express myself, the extremities of the nerves which unite in a certain part of the brain, perceives all the impressions made upon the nerves, and arrives at the knowledge of the external objects which have made these impressions on the organs of sense. Though we do not know wherein consists the resemblance of the impressions made on the extremities of the nerves, with the objects themselves which occasioned them, they are, however, very proper to supply the soul with a very just idea of them.

The action by which the soul, operating on the extremities of the nerves, can put in motion at pleasure the members of the body, may be compared to that of a player on puppets, who, by pulling a string, makes them strut about, and move their limbs as he pleases. This comparison is, however, very imperfect; for the union of the soul and body is infinitely more intimate.

The soul is not so indifferent, in respect to feeling, as the man placed in the dark room; it is much more deeply interested in what is going on. There are sensations highly agreeable to it, and others very disagreeable, and even painful. What more disagreeable than acute pain, though it proceed but from a bad tooth? This, however, is no more than a nerve irritated in a certain manner; and yet it excites in the soul pain intolerable.

In whatever light we consider the strict union of soul and body, which constitutes the essence of a living man, it must ever remain an inexplicable mystery; and in all ages philosophers have taken fruitless pains, in the hope of arriving at a satisfactory solution. Various systems have been devised for this purpose.

The first is, that by which a real influence is established of body on soul, and of soul on body; so that the body, by means of the senses, supplies the soul with its first perceptions of external things; and that the soul, by acting immediately on the nerves, in their origin, excites in the body the motion of its members; though it is at the same time acknowledged that the manner of this mutual influence is absolutely unknown to us. We must undoubtedly have recourse to the omnipotence of God, who has given to every soul a power over the portion of matter containing the extremities of the nerves of the body, so that the power of every soul is restricted to a small part of the body, whereas the power of God extends to all the bodies of the universe. This system seems the most conformable to truth, though we are very far from pretending to have a particular knowledge of it.

The other two systems are the invention of philosophers, who boldly deny the possibility of a real influence of spirit upon bodies; though they are under the necessity of allowing it to the Supreme Being. According to them, the body cannot supply the soul with the first ideas of external things, nor the soul produce any motion in the body.

One of these two systems was the invention of *Descartes;* it goes by the name of *the system of occasional causes.* According to this philosopher, when the organs of sense are excited by exterior bodies, God immediately impresses on the soul, at the same instant, the ideas of these bodies; and when the soul wills that any member of this body should move, still it is God who immediately impresses on that member the motion desired; but all the while the soul is in no manner of connexion with its body. It was, therefore, altogether unnecessary that the body should be a machine of such admirable construction, as the dullest mass would have answered the purpose equally well.

This system, accordingly, soon lost much of its credit, when the celebrated *Leibnitz* substituted in its place that of the pre-established harmony, which you have no doubt frequently heard mentioned in conversation.

According to this system of *pre-established harmony*, the soul and the body are two substances out of all connexion, and exercising no manner of influence on each other. The soul is a spiritual substance, which, from its own nature, receives, or assumes, all its ideas, its thoughts, its perceptions, without the body's having the least share in the matter; and the body is a machine most ingeniously constructed, like a clock, which produces all its motions in succession, without any manner of influence on the part of the soul. But God, having foreseen from the beginning all the resolutions which every soul would at every instant form, arranged the machine of the body so that its motions should, at every instant, harmonize with the resolutions of the soul. Thus, when I at this moment raise my hand, *Leibnitz* says that God, having foreseen my soul would will, at this moment, my hand to be raised, disposed the machine of my body in such a manner, that in virtue of its proper organization my hand should necessarily rise at the same instant; and, in like manner, that all the motions of the members of the body are performed in virtue of their proper organization, which has been from the beginning so disposed as to be at all times in harmony with the determinations of the soul.

6th December, 1760.

LETTER LXXXIII.

Examination of the System of pre-established Harmony. An Objection to it.

There was a time when the system of pre-established harmony had acquired such a high reputation over all Germany, that to dare to call it in question was to incur the imputation of ignorance, or bigotry. The supporters of this system boasted, that by means of it the omnipotence and omniscience of the Supreme Being were set in their clearest light, and that it was impossible for any one who believed in these exalted perfections of God to entertain a doubt of the truth of this sublime system.

In fact, say they, we see that poor pitiful mortals are capable of constructing machines so ingeniously as to fill the vulgar spectator with astonishment: how much stronger reason, then, have we to admit that God, having known from all eternity all that my soul would wish and desire, at every instant, should have been able to construct such a machine, which, at every instant, should produce motions conformable to the determinations of my soul! Now, this machine is precisely my body, which is united to my soul only by this harmony; so that if the organization of my body were deranged to such a degree as to be no longer in harmony with my soul, this body would no more belong to me than the body of a rhinoceros in the heart of Africa: and if, in the case of a derangement of my body, God should adjust that of a rhinoceros so that its motions were in such harmony with the determinations of my soul as to raise its paw at the moment I willed it, this body would then be mine, and would belong to my soul, as my present body now belongs to it, without

having undergone itself, on that account, any change whatever.

Mr. Leibnitz himself has compared the soul and the body to two clocks, which continually indicate the same hour. A clown who should see this beautiful harmony of these two clocks would undoubtedly conclude that they acted upon each other; but he would be under a mistake, for the one performs its motions independently of the other. The soul and the body are likewise two machines totally independent, the one being spiritual, the other material; but their operations are always in a harmony so complete, that we are induced to believe them to belong to each other, and that the one has a real influence upon the other, which is, however, a mere illusion.

In order to form a judgment of this system, I remark, first, That it cannot be denied to be possible for God to create a machine which should be always in harmony with the operations of my soul; but it appears to me that my body belongs to me by other rights than such a harmony, however beautiful it may be: and I believe you will not be disposed hastily to adopt a system which is founded on this principle alone, that no spirit can act upon a body; and that, reciprocally, a body cannot act upon, or supply ideas to, a spirit. This principle is, besides, destitute of all proof, the chimeras of its partisans respecting simple beings having been completely refuted. And if God, who is a spirit, has the power of acting upon bodies, it is not absolutely impossible that a spirit, such as the human soul, should be able likewise to act upon a body. Accordingly, we do not pretend to say that our soul acts upon all bodies, but only upon a small particle of matter, with respect to which it has received the power of God himself, though to exercise it in a manner which we are utterly unable to comprehend.

Further, the system of pre-established harmony labours under other great difficulties. According to it the soul derives all its knowledge from its own proper fund, without any contribution on the part of the body and the senses. Thus, when I read in the gazette that the pope is dead, and I come to the knowledge of the pope's death, the gazette and my reading have nothing to do with the communication of this knowledge, as these circumstances respect only my body and my senses, which have no manner of connexion with my soul. But, conformably to this system, my soul derives, at the same time, from its own proper fund the ideas which it has of this same pope. It concludes he must absolutely be dead, and this knowledge comes to it with the reading of the gazette, so that I imagine the reading of the gazette furnished me with this knowledge, though I really derived it from the proper fund of my soul.

But this idea is perfectly absurd. How was it possible for me so boldly to assert that the pope must necessarily have died at the moment mentioned in the gazette, and that only from the idea which I had of the pope's condition and health, though perhaps I knew nothing about him, while I am infinitely better acquainted with my own situation, without knowing, however, what shall befall me to-morrow.

In like manner, when you do me the honour to read these letters, and derive the knowledge of some truth from them, it is your soul which extracts that truth from its own proper fund, without my contributing at all to it by my letters. The reading of them serves only to maintain the harmony which the Creator meant to establish between the soul and the body. It is only a formality altogether superfluous with respect to the knowledge itself. I shall nevertheless continue to tender you my instructions.

9th December, 1760.

LETTER LXXXIV.

Another Objection.

There is another objection to be made to the system of pre-established harmony; namely, that it is utterly destructive of human liberty. In fact, if the bodies of men are machines, similar to a watch, all their actions are a necessary consequence of their construction. Thus, when a thief steals my purse, the motion made by his hands is an effect as necessary of the machine of his body, as the motion of the hand of my clock, now pointing to nine. You will readily comprehend what must be the conclusion. As it would be unjust, nay ridiculous, to think of being angry at the clock, and of chastising it, because it pointed to nine, it would be equally so with respect to the thief, whom it would be absurd to punish for having stolen my purse.

Of this we had a well-known example in the reign of his late majesty, when *Mr. Wolff* taught at Halle the system of the pre-established harmony. The king informed himself of this doctrine, which was then making a prodigious noise; and one of his court having suggested to him that according to *Mr. Wolff's* doctrines soldiers were mere machines, and that when one deserted it was a necessary consequence of his particular structure, and therefore ought not to subject him to punishment, as would be the case were a machine an object of punishment, for having performed such and such a motion; the king was so provoked at this representation, that he gave orders to banish *Wolff* from Halle, with certification, that if he was found there at the end of twenty-four hours, he should be hanged up. The philosopher upon this took refuge at Marburg, where I conversed with him soon after.

But the partisans of this system have always maintained that the pre-established harmony by no means encroached on human liberty. They admit that the exterior actions of men are necessary effects of the organization of the body, and that, in this respect, they take place as necessarily as the motions of a watch: but that the mental determination enjoyed perfect liberty: that these may be deserving of punishment, though the corporeal action was necessary; that the criminality of an action consists less in the act, or motions of the body, than in the resolution or intention of the soul, which remains entirely free. Let us conceive, say they, the soul of a thief, determining, at a certain time, to commit a robbery: God, having foreseen this intention, has provided it with a body, organized in such a manner as to produce, precisely at the same time, the motions requisite for the commission of this robbery: the action, say they, is itself the necessary effect of the organization of the body, but that the intention of the thief is a free act of his soul, which is not, on that account, less culpable and less punishable.

Notwithstanding this reasoning, the supporters of the system of pre-established harmony will always find themselves very much embarrassed to maintain the liberty of the determination of the soul. For, according to them, the soul is itself similar to a machine, though of a nature totally different from that of the body; the representations produced in it are occasioned by those which precede, and these again by others anterior to them, and so on, so that they follow each other as necessarily as the motions of a machine. In fact, say they, men act always from certain motives, founded on the representations of the soul, which succeed each other, conformably to its state.

You will recollect that, according to this system, the soul derives no one idea from the body, not

being in any real connexion with it; but all from its own proper fund. Present ideas flow from those which preceded, and are a necessary consequence of them; so that the soul is nothing less than master of its own ideas, which generates its resolutions, and which are therefore as little under its power; and consequently all its actions are founded on its present state—that on the immediately preceding, and so on, are a necessary effect of the first state in which it was created, over which it certainly could have no power, and of consequence could not be free. In depriving men of their liberty, all their actions become necessary, and can no longer be considered as either right or criminal.

No one of these philosophers has hitherto been able to remove these difficulties; and their adversaries have a right to object to them, that this opinion is subversive of all morality, and makes every crime which men commit to recoil on God himself, which is undoubtedly the grossest impiety. We must not, however, load them with the imputation of such consequences, though they flow very naturally from their principles. The article of liberty is a stumbling-block in philosophy; and it is extremely difficult to steer clear of the dangers which press on all sides.

13*th December*, 1760.

LETTER LXXXV.

Of the Liberty of Spirits; and a Reply to Objections against Liberty.

THE greatest difficulties on the subject of liberty, even those which appear insurmountable, arise from want of distinguishing with sufficient attention between the nature of spirit and that of body. The Wolfian philosophers even go so far as to put spirits and the elements of body on the same footing, and give to both the one and the other the name of *monads*, the nature of which, according to them, consists in the power of changing their state; from whence result all the changes in bodies, and all the representations and actions of spirits.

Since, then, in this system, the actual state of bodies and of spirits derives its determination from that which immediately preceded, and as the actions of spirits are derived, like those of bodies, from their preceding state, it is evident that liberty is no more an attribute of spirit than it is of body. As to body, it is impossible to conceive the least shadow of liberty in it; for liberty always supposes the power of committing, of admitting, or of suspending an action, and this is directly opposite to all that passes in body. Would it not, then, be ridiculous to expect that a watch should point to any other hour than what it actually does, and to think of punishing it on that account? Would it not be absurd to fly into a passion at a puppet, because, after several other gestures, it had turned its back to us?

All the changes which take place in bodies, and which are all reducible to their state of rest, or of motion, are the necessary consequence of the powers which act upon them; and their action once admitted, no changes in bodies can take place but precisely such as do take place: what respects body, therefore, is an object of neither praise nor blame. However ingeniously a piece of mechanism may be constructed, the commendation which we bestow upon it reverts to the artist; the machine itself has no interest in what passes; the artist, too, is alone responsible for the defects of a clumsy and awkward machine; the machine itself is perfectly innocent. While, therefore, the inquiry is restricted to bodies, they are clearly in no respect responsible; no reward, no punishment can possibly attach to them;

all the changes and motions produced in them are the necessary consequences of their structure.

But spirits are of a very different nature, and their actions depend on principles directly opposite. Liberty, entirely excluded from the nature of body, is the essential portion of spirit to such a degree that without liberty a spirit could not exist; and this it is which renders it responsible for its actions. This property is as essential to spirit as extension or impenetrability is to body; and as it would be impossible for the Divine Omnipotence itself to divest body of these qualities, it would be equally impossible for it to divest spirits of liberty. A spirit without liberty would no longer be a spirit, as a body without extension would no longer be a body.

It has in all ages been a subject of eager inquiry among philosophers, how God could have permitted sin to enter into the world? Had they reflected that the souls of men are beings necessarily free from their very nature, the controversy would have been easily settled.

The objections commonly made to human liberty are these: a spirit, it is said, or a man, is never determined to an action but from motives; and after having carefully weighed the reasons on both sides, he finally decides in favour of that which he deems the preferable. Hence they conclude that motives determine the actions of men, just as the motion of a ball on the billiard-table is determined by the stroke impressed upon it, and that the actions of men are no more free than the motion of the ball. But it must be considered that the motives which engage a man to undertake any enterprise refer very differently to the soul from what the stroke does to the ball. The stroke produces its effect necessarily; but a motive, however powerful, prevents not the action from being voluntary. I had very powerful motives to undertake a journey to Magdeburg—a regard to my promise—the prospect of enjoying the felicity of paying my respects to your highness; but I am perfectly sensible, at the same time, that I was not forced to it; and that it was entirely in my own power to take that journey, or to have remained at Berlin. But a body impelled by any power necessarily obeys, and it cannot be affirmed that it was at liberty to obey or not as it pleased.

The motive which determines a spirit to regulate its resolves is of a nature wholly different from a *cause* or *force* acting upon body. Here the effect is produced necessarily, and there the effect remains always voluntary, and the soul has power over it. On this is founded the *imputability* of the actions of a spirit, which makes it responsible for them, and which is the true foundation of right and wrong. As soon as we have settled this infinite difference between spirit and body, the question respecting liberty presents very little difficulty.

16*th December*, 1760.

LETTER LXXXVI.

The same Subject continued.

The difference which I have just established between the *motives* conformably to which spirits act, and the *causes* or *powers* which act on bodies, discovers to us the true foundation of liberty.

Imagine a puppet so artfully constructed with wheels and springs as to be able to approach my pocket and to pick out my watch without my perceiving it. This action, being a necessary consequence of the organization of the machine, could not be considered as a robbery; and I should render myself ridiculous if I got into a passion at it, and insisted on having the machine hanged. Every one would say that the puppet was innocent, and incapable of committing a blameable action; it would be, besides, equally indifferent to the puppet to be hanged or placed on a throne. But if the artist had contrived this machine on purpose to steal and to enrich himself by such means, however much I might admire the ingenuity displayed on the mechanism, I should reckon myself obliged to bring him to justice as a thief. It follows, then, that even in this case the criminality reverts upon an intelligent being, or a spirit, and that spirits alone are responsible for their actions.

Let every man examine his own actions, and he will always find that he was not forced into them, though he might be induced by motives. If his actions are commendable, he is perfectly conscious of meriting the praises bestowed upon him. However he might be deceived in his other judgments, he cannot in this case; the sentiment of his liberty is so intimately connected with that liberty itself that they are inseparable. It is possible to entertain a doubt where the liberty of another is concerned, but it is impossible ever to be deceived respecting one's own. A clown, for example, on seeing the puppet above described, might easily imagine it to be a real thief, and that it likewise was a free agent: in this he would be mistaken; but with respect to his own liberty it is impossible for him to mistake; as he deems himself free, he is so in fact. It might likewise happen that the clown in question, undeceived as to the puppet, should afterward consider a dexterous thief as a machine, destitute of all sentiment and of liberty: here he would fall into the opposite error; but as to his own actions he will never be mistaken.

It would therefore be ridiculous to affirm that it might be possible for a watch to imagine that its hand turned freely, and to believe that it now points to nine because it pleases to do so, but could point to any other hour if it thought proper: the watch would undoubtedly deceive itself. But the whole supposition is manifestly absurd. You must first ascribe to the watch sentiment and imagination, and accordingly suppose it a spirit or soul, which necessarily implies liberty; and afterward consider it as a mere machine, divested of liberty, which is a manifest contradiction.

Another objection, however, is started against liberty, founded on the Divine *prescience*. God, it is said, foresaw from all eternity every resolution which I should form, and every action which I should do during every instant of my life. If God foresaw I should just now continue to write, that I should by-and-by lay down my pen, and rise to take a walk, my action would be no longer free, for I am under the necessity of writing, of laying down the pen, and of rising to walk; and it would be impossible for me to act otherwise, as it was impossible God should be deceived in what he foresees.

The reply is obvious. Because God foresaw, from all eternity, that I should perform, on such a day, such an action, it does not follow that I shall perform it because God foresaw it. For it is evident that it ought not be alleged, in the cause supposed, that I go on to write, *because* God foresaw I should go on to write; but, on the contrary, as I judge it proper to go on to write, God foresaw that I would do so. Thus the prescience of God by no means encroaches on my liberty; and all my actions remain equally at liberty, whether God foresaw them or not.

Some, however, in the view of supporting liberty, have gone so far as to deny the Divine prescience; but you will have little difficulty in detecting the falsehood of this opinion. Is it so surprising that the Supreme Being, who is acquainted with all my propensities, should be able to foresee the effect which every motive will produce on my soul, and, consequently, all the resolutions which I shall form in conformity to these effects, when simple mortals, such as we are, frequently exercise a similar prescience? You can easily imagine to yourself a man extremely covetous, who has a fair opportunity of making a considerable advantage. You know for certain he will not fail to avail himself of it. Your knowledge of this, however, has no influence upon the man; he goes into it with the full determination of his own mind, as if you had never spent a thought upon him. Now, as God is infinitely better acquainted with men, and all their dispositions, it is not to be doubted that he could have foreseen their actions, in all situations. The prescience of God, with respect to the free actions of spirits, is nevertheless founded on another principle than that of the changes which *must* take place in the corporeal world, where all is under the power of necessity. This distinction shall be the subject of my next Letter.

20*th December*, 1760.

LETTER LXXXVII.

Influence of the Liberty of Spirits upon Events.

If the world contained bodies only, and if the changes which take place in it were necessary consequences of the laws of motion, conformably to the powers with which they act upon each other, all events would be necessary, and would depend on the first arrangement which the Creator had established of the bodies of the universe; so that this arrangement once established, it should be impossible for other events afterward to take place than those which happen in the actual order of things. The world would undoubtedly be in this case a mere machine, similar to a watch, which, once wound up, afterward produces all the motions by which we measure time.

Imagine to yourself a musical clock; such a clock once regulated, all the motions which it performs, and the airs which it plays, are produced in virtue of its construction, without any fresh application of the hand of the master, and in that case we say it is done mechanically. If the artist touches it, by changing the notch, or the cylinder, which regulates the airs, or by winding it up, it is an external action, which, not being founded on the organization of the machine, no longer appertains to it. And if God, as Lord of the universe, should change immediately any thing in the course of successive events, this change would no longer appertain to the machine: it would then be a *miracle*.

A miracle, consequently, is an immediate effect of the divine Omnipotence, which could not have taken place had God left the machine of the universe freely to take its course. Such would be the state of the universe if it contained bodies only; in that case it might be said, that all events take place in it from an absolute necessity, each of them being a necessary effect of the structure of the universe; unless it pleased God to work miracles.

The same thing would happen, on admitting the system of pre-established harmony, though it allows the existence of spirits; for, according to this system, spirits do not act upon bodies, but these perform all their motions and actions only in virtue of their structure, once established; so that when I raise my arm, this motion is an effect as necessary of the organization of my body as that of the wheels in a watch. My soul in no respect contributes to it; it is God who, from the beginning, arranged the matter, so that the action of my body must necessarily result from it, at a certain time, and raise the arm at the instant that my soul willed it. Thus, my soul has no influence upon my body, any more than upon those of other men and of animals; and, consequently, according to this system,

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may afterward operate on other bodies, and these again on others, so that the slightest motion of my body may have a great influence on a multitude of events.

Man, however, though master of the first motion of his body which occasions these events, is not so of the consequences of his actions. These depend on so many circumstances, that the most sagacious mind is incapable of foreseeing them: accordingly, we every day see the best concerted projects failing. But it is here that we must acknowledge the government and providence of God, who, having from all eternity foreseen all the counsels, the projects, and the voluntary actions of men, arranged the corporeal world in such a manner that it brings about, at all times, circumstances which cause those enterprises to fail or to succeed, according as his infinite wisdom judges to be most fit. God thus remains absolute sovereign of all events, notwithstanding the liberty of men, all whose actions, though free, are from the beginning part of the plan which God intended to execute when he created this universe.

This reflection plunges us into an abyss of wonder and adoration at the infinite perfections of the Creator; while we consider that there is nothing so mean in itself as not to be, from the beginning of the world, an object worthy of entering into the original plan which God proposed to himself.

23*d December*, 1760.

LETTER LXXXVIII.

Of Events, Natural, Supernatural, and Moral.

In common life we carefully distinguish events produced by corporeal causes from those in which men and animals co-operate. Those of the former description are denominated *natural events*, or produced by natural causes; such are the phenomena of the heavenly bodies, eclipses, tempests, whirlwinds, earthquakes, &c. These are called natural phenomena, because it is understood that neither men nor animals are active in the production of them.

If we see a tree torn up by the roots, through the violence of the wind, we call it a natural effect; but if it were done by the strength of man, or the proboscis of an elephant, no one would call this a natural effect. When our plains are deluged by an inundation, or destroyed by the hail, we say the cause of this calamity was natural; but if the mischief were done by the invasion of an enemy, we would no longer deem the cause of it to be natural.

If such an evil were to be produced by a miracle, or by the immediate power of God, we would say the cause of it was *supernatural;* but if the event were occasioned by men or animals, we would not, in that case, give it the name of either natural or supernatural. We would characterize such an event simply by the name of *action*, which denotes an effect that is neither natural nor supernatural. It might with greater propriety be denominated *moral*, as it depends on the liberty of an intelligent agent.

Thus, when Quintus Curtius gives us a detail of the actions of Alexander the Great, he communicates to us the knowledge of the events brought about by the voluntary determinations of that hero. Such an action always supposes freedom of resolution in a spiritual being; a power of determination which depends upon his will, and of which he is master. I say, of which he is master; for there is a great variety of motions, the production of which, were we to determine to will them ever so much, we should not, however, be obeyed, because over such movements we have no power.

I am not master even of all the motions performed in my own body; that of my heart and of my blood is not subject to my power, or to the empire of my soul, as the action which I perform when I write this letter. There are other motions which partake of the nature of both these, such as respiration, which it is in my power to accelerate or to retard to a certain degree, but of which I am by no means the absolute master.

Language is not sufficiently rich to express, by one appropriate term, all these different kinds of events. There are some produced by natural causes merely, and which are necessary consequences of the arrangement of bodies in the universe; and as these necessarily come to pass, the knowledge of this arrangement enables us to foretel a great number of them, such as the situation of the heavenly bodies, eclipses, and other phenomena depending on them, for any given time whatever. There are other events which depend only on the will of free and spiritual beings, as the actions of every man and of every animal. It is impossible for us to foresee any thing of these, in particular, unless by conjecture merely; and in this we are frequently very grossly mistaken. God alone possesses this knowledge in a supreme degree.

From these two kinds of events there arises a third, in which natural causes concur with such as are voluntary, and dependent on a being exercising its liberty. Of this the billiard-table furnishes an example. The strokes impressed on the balls depend on the will of the players; but as soon as motion is communicated to them, the continuation of that motion, and their collision with each other, or with the cushion, are necessary consequences of the laws of motion.

In general, most of the events which take place on the earth must be referred to this species, as there are scarcely any over which men and animals have not some influence. The cultivation and produce of our fields require, in the first instance, the voluntary exertions of men or beasts; but the sequel is an effect of causes purely natural. It is accordingly of importance to remark, that God acts in a manner totally different towards bodies and spirits. God has established for bodies laws of rest and motion, conformably to which all changes *necessarily* take place; as bodies are merely passive beings, which preserve themselves in their state, or necessarily obey impressions made upon them by others, as I formerly explained; whereas spirits are susceptible of no force or constraint, but are governed of God by precepts and prohibitions.

With respect to bodies, the will of God is always perfectly accomplished; but with respect to spiritual beings, such as men, the contrary very often happens. When it is said to be the will of God that men should love one another, we mean by that expression a commandment which men ought to obey; but this is very far from being the case. God does not force men to it, for this would be contrary to the liberty which is essential to them; but He endeavours to engage men to the observance of this commandment, by proposing to them motives the most powerful; but it always depends on the will of man whether he is to obey or not. In this sense we are to understand the will of God, when it refers to the free actions of spiritual beings.

27th December, 1760.

LETTER LXXXIX.

Of the Question respecting the best World possible; and of the Origin of Evil.

You know well, that it has been made a question, Whether this world be the best possible? It cannot be doubted, that the world perfectly corresponds to the plan which God proposed to himself when he created it.

As to bodies and material productions, their arrangement and structure are such, that certainly they could not have been better. Please to recollect the wonderful structure of the eye, and you will see the necessity of admitting that the conformation of all its parts is perfectly adapted to fulfil the end in view, that of representing distinctly exterior objects. How much address is necessary to keep up the eye in that state, during the course of a whole life? The juices which compose it must be preserved from corruption; it was necessary to make provision that they should be constantly renewed and maintained in a suitable state.

A structure equally marvellous is observable in all the other parts of our bodies, in those of all animals, and even of the vilest insects. And the structure of these last is so much the more admirable, on account of their smallness, that it should perfectly satisfy all the wants which are peculiar to each species. Let us examine only the sense of seeing in these insects, by which they distinguish objects so minute, and so near, as to escape our eyes, and this examination alone will fill us with astonishment.

We discover the same perfection in plants; every thing in them concurs to their formation, to their growth, and to the production of their flowers, of their fruits, or of their seeds. What a prodigy, to behold a plant, a tree, spring from a small grain cast into the earth, by the help of the nutritious juices with which the soil supplies it! The productions found in the bowels of the earth are no less wonderful: every part of nature is capable of exhausting our utmost powers of research, without permitting us to penetrate all the wonders of its construction. Nay, we are utterly lost, while we reflect how every substance—earth, water, air, and fire—concur in the production of all organized bodies; and finally, how the arrangement of all the heavenly bodies is so admirably contrived as perfectly to fulfil all these particular destinations.

After having reflected in this manner, it will be difficult for you to believe that there should have been men who maintained, that the universe was the effect of mere chance, without any design. But there always have been, and there still are, persons of this description; those, however, who have a solid knowledge of nature, and whom fear of the justice of God does not prevent from acknowledging Him, are convinced, with us, that there is a Supreme Being who created the whole universe, and, from the remarks which I have just been suggesting to you respecting bodies, every thing has been created in the highest perfection.

As to spirits, the wickedness of man seems to be an infringement of this perfection, as it is but too capable of introducing the greatest evils into the world; and these evils have, at all times, appeared incompatible with the sovereign goodness of God. This is the weapon usually employed by infidels against religion, and the existence of God. If God, say they, was the author of the world, He must also be the author of the evil which it contains, and of the crimes committed in it.

This question, respecting the origin of evil—the difficulty of explaining how it can consist with the sovereign goodness of God, has always greatly perplexed philosophers and divines. Some have endeavoured to give a solution, but it has satisfied only themselves. Others have gone so far as to maintain that God was, in fact, the author of moral evil, and of crimes; always protesting, at the same time, that this opinion ought to bring no imputation on the goodness and holiness of God. Others, finally, consider this question as a mystery which we cannot comprehend; and these last, undoubtedly, have embraced the preferable sentiment.

God is supremely good and holy; He is the author of the world, and that world swarms with crimes and calamities. These are three truths which it is apparently difficult to reconcile; but, in my opinion, a great part of the difficulty vanishes as soon as we have formed a just idea of spirit, and of the liberty so essential to it that God himself cannot divest it of this quality.

God having created spirits, and the souls of men, I remark, first, that spirits are beings infinitely more excellent than bodies; and, secondly, that, at the moment of creation, spirits were all good: for time is requisite to the formation of evil inclinations: there is, therefore, no difficulty in affirming that God created spirits. But it being the essence of spirits to be free, and liberty not being capable of subsisting without a power to sin, to create a spirit possessed of the power of sinning has nothing inconsistent with divine perfection, because a spirit could not be created destitute of that power.

God has, besides, done every thing to prevent crimes, by prescribing to spirits precepts, the observance of which must always render them good and happy. There is no other method of treating spirits, which cannot be subject to any constraint; and if some of them have abused their liberty, and transgressed these commandments, they are responsible for it, and worthy of punishment, without any impeachment of the Deity.

There remains only one objection more to be considered—namely, that it would have been better not to create such spirits, as God foresaw they must sink into criminality. But this far surpasses human understanding; for we know not whether the plan of the world could subsist without them. We know, on the contrary, by experience, that the wickedness of some men frequently contributes to the correction and amendment of others, and thereby conducts them to happiness. This consideration alone is sufficient to justify the existence of evil spirits. And as God has all power over the consequences of human wickedness, every one may rest assured, that in conforming to the commandments of God, all events which come to pass, however calamitous they may appear to him, are always under the direction of Providence, and finally terminate in his true happiness.

This providence of God, which extends to every individual in particular, thus furnishes the most satisfactory solution of the question respecting the permission and the origin of evil. This likewise is the foundation of all religion, the alone "object of which is to promote the salvation of mankind."*

30*th December*, 1760.

LETTER XC.

Connexion of the preceding Considerations with Religion. Reply to the Objections of the Philosophical Systems against Prayer.

Before I proceed farther in my lessons on philosophy and physics, I think it my duty to point out to you their connexion with religion.

However extravagant and absurd the sentiments of certain philosophers may be, they are so obstinately prepossessed in favour of them, that they reject every religious opinion and doctrine which is not conformable to their system of philosophy. From this source are derived most of the sects and heresies in religion. Several philosophical systems are really contradictory to religion; but in that case divine truth ought surely to be preferred to the reveries of men, if the pride of philosophers knew what it was to yield. Should sound philosophy sometimes seem in opposition to religion, that opposition is more apparent than real; and we must not suffer ourselves to be dazzled with the speciousness of objection.

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* It is remarkable that a writer who so fully recognises the providence of an all-wise Creator, and who appears to refer to the Bible when he says, "God has done every thing to prevent crimes, by prescribing to spirits *precepts*, the observance of which must always render them good and happy," should, in reference to the origin of evil, neglect altogether the cause assigned for it in more inspired writings. Every attempt to elucidate this subject by mere philosophical reasoning, independent of the authority of the Bible, must, we apprehend, utterly fail.—*Am. Ed.*

I begin with considering an objection which almost all the philosophical systems have started against prayer. Religion prescribes this as our duty, with an assurance that God will hear and answer our vows and prayers, provided they are conformable to the precepts which he has given us. Philosophy, on the other hand, instructs us that all events take place in strict conformity to the course of nature, established from the beginning, and that our prayers can effect no change whatever; unless we pretend to expect that God should be continually working miracles, in compliance with our prayers. This objection has the greater weight, that religion itself teaches the doctrine of God's having established the course of all events, and that nothing can come to pass but what God foresaw from all eternity. Is it credible, say the objectors, that God should think of altering this settled course, in compliance with any prayers which men might address to him?

But I remark, first, that when God established the course of the universe, and arranged all the events which must come to pass in it, he paid attention to all the circumstances which should accompany each event; and particularly to the dispositions, to the desires, and prayers of every intelligent being; and that the arrangement of all events was disposed in perfect harmony with all these circumstances. When, therefore, a man addresses to God a prayer worthy of being heard, it must not be imagined that such a prayer came not to the knowledge of God till the moment it was formed. That prayer was already heard from all eternity; and if the Father of Mercies deemed it worthy of being answered, he arranged the world expressly in favour of that prayer, so that the accomplishment should be a consequence of the natural course of events. It is thus that God answers the prayers of men without working a miracle.

The establishment of the course of the universe, fixed once for all, far from rendering prayer unnecessary, rather increases our confidence, by conveying to us this consolatory truth, that all our prayers have been already, from the beginning, presented at the feet of the throne of the Almighty, and that they have been admitted into the plan of the universe, as motives conformably to which events were to be regulated, in subserviency to the infinite wisdom of the Creator.

Can any one believe that our condition would be better if God had no knowledge of our prayers before we presented them, and that He should then be disposed to change in our favour the order of the course of nature? This might well be irreconcilable to his wisdom, and inconsistent with his adorable perfections. Would there not, then, be reason to say that the world was a very imperfect work? that God was entirely disposed to be favourable to the wishes of men; but not having foreseen them, was reduced to the necessity of every instant interrupting the course of nature, unless He were determined totally to disregard the wants of intelligent beings, which, nevertheless, constitute the principal part of the universe? For to what purpose create this material world, replenished with so many great wonders, if there were no intelligent beings, capable of admiring it, and of being elevated by it to the adoration of God, and to the most intimate union with their Creator, in which, undoubtedly, their highest felicity consists?

Hence, it must absolutely be concluded, that intelligent beings and their salvation must have been the principal object, in subordination to which God regulated the arrangement of this world; and we have every reason to rest assured that all the events which take place in it are in the most delightful harmony with the wants of all intelligent beings, to conduct them to their true happiness; but without constraint, because of their liberty, which is as essential to spirits as extension is to body. There is therefore no ground for surprise that there should be intelligent beings which shall never reach felicity.

In this connexion of spirits with events consists the Divine Providence, of which every individual has the consolation of being a partaker; so that every man may rest assured that, from all eternity, he entered into the plan of the universe. How ought this consideration to increase our confidence and our joy in the providence of God, on which all religion is founded! You see, then, that on this side religion and philosophy are by no means at variance.

3d January, 1761.

LETTER XCI.

The Liberty of Intelligent Beings in Harmony with the Doctrines of the Christian Religion.

Liberty is a quality so essential to every spiritual being, that God himself cannot divest them of it, just as He cannot divest a body of its extension, or of its *inertia*, without entirely destroying or annihilating it: to divest a spirit of liberty, therefore, would be the same thing as to annihilate it. This must be understood of the spirit or soul itself, and not of the actions of the body which the soul directs in conformity to its will. If you would prevent me from writing, you have but to bind my hands—to write is undoubtedly an exercise of liberty; but then, though you may say that you have deprived me of the liberty of writing, you have only deprived my body of the faculty of obeying the dictates of my soul. Bind me ever so hard, you cannot extinguish in my spirit an inclination to write; all you can do is to prevent the execution of it.

We must always carefully distinguish between inclination, or the act of willing, and execution, which is performed by the ministration of the body. The act of willing cannot be restrained by an exterior power, not even by that of God; for liberty is independent of all exterior force. But there are means of acting on spirits, by motives which have a tendency, not to constrain, but to persuade. Let a man be firmly determined to engage in any enterprise, and let us suppose the execution of it prevented; without making any change in his intention, or will, it might be possible to suggest motives which should engage him to abandon his purpose, without employing any manner of constraint: however powerful these motives may be, he is always master of his own will; it never can be said that he was forced or constrained to it, at least the expression would be improper; for the proper term is *persuade*, which is so suitable to the nature and the liberty of intelligent beings, that it cannot be applied to any other. It would be very ridiculous, for example, in playing at billiards, to say that I persuaded the ball to run into the hazard.

This sentiment respecting the liberty of spirits appears, however, to some persons contrary to the goodness or the power of the Supreme Being. Liberty, from its very nature, can submit to no degree of constraint, even on the part of God. But without exercising any constraint over spirits, God has an infinite variety of means of presenting them with persuasive motives; and I believe that all possible cases are adapted by Providence to our condition, in such a manner that the most abandoned wretches might derive from them the most powerful motives to conversion, if they would but listen to them: and that a miracle would not produce a better effect on these vicious spirits; they might be affected by it for a season, but would not become better. It is thus that God co-operates in our conversion, by furnishing us with motives the most efficacious, and by the circumstances and opportunities which His providence supplies.

If, for example, a man who hears an awakening sermon is affected by it, repents, and is converted, the act of his soul is evidently his own work; but the occasion of the sermon, which he was so happy as to hear precisely at the time when he was disposed to profit by it, was nothing less than His work; the Divine Providence overruled that circumstance, so salutary to him. In fact, without the opportunity, over which the man had no power, he would have persisted in a sinful course.

Hence you will easily comprehend the meaning of such expressions as these: "Man can do nothing of himself; all depends on divine grace: it is God that worketh to will and to do." The favourable circumstances which Providence supplies to men are sufficient to elucidate these expressions, without having recourse to a secret force, which acts by constraint on human liberty; as these circumstances are directed of God, in conformity to the most consummate wisdom, in the view of conducting every intelligent being to happiness and salvation, unless he wilfully rejects the means by which he might have attained true felicity.*

6th January, 1761.

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* The reader must look in vain in this letter for any account of the Christian religion announced in its caption.—*Am. Ed.*

LETTER XCII.

Elucidation respecting the Nature of Spirits.

In order more clearly to elucidate what I have just said respecting the difference between body and spirit—for it is impossible to be too attentive to what constitutes that difference, as it extends so far, that spirit has nothing in common with body, nor body with spirit—I think it necessary to subjoin the following reflections;

Extension, *inertia*, and impenetrability are the properties of body: spirit is without extension, without *inertia*, without impenetrability. All philosophers are agreed that extension cannot have place in respect of spirit. It is a self-evident truth, for every thing extended is divisible, and you can form the idea of its parts; but a spirit is susceptible of no division; you can have no conception of its half, or of its third part. Every spirit is a complete being, to the exclusion of all parts; it cannot then be affirmed that a spirit has length, breadth, or thickness. In a word, all that we conceive of extension must be excluded from the idea of a spirit.

It would appear, therefore, that as spirits have no magnitude, they must resemble geometrical points, the definition of which is, that they have neither length, breadth, nor depth. Would it be a very accurate idea to represent to ourselves a spirit by a mathematical point? The scholastic philosophers have professed this opinion, and considered spirits as beings infinitely small, similar to the most subtile particles of dust, but endowed with an inconceivable activity and agility, by which they are enabled to transport themselves in an instant to the greatest distances. They maintained, that in virtue of this extreme minuteness, millions of spirits might be

enclosed in the smallest space; they even made it a question, How many spirits could dance on the point of a needle?

The disciples of *Wolff* are nearly of the same opinion. According to them, all bodies are composed of particles extremely minute, divested of all magnitude—and they give them the name of monads. A monad, then, is a substance destitute of all extension; and on dividing a body till you come to particles so minute as to be susceptible of no farther division, you have got to the Wolffian monad, which differs, therefore, from the most subtile particle of dust only in this, that the minutest particles of dust are not perhaps sufficiently small, and that a farther division is still necessary to obtain real monads.

Now, according to *Mr. Wolff*, not only all bodies are composed of monads, but every spirit is merely a monad; and the Supreme Being, I tremble as I write it, is likewise a monad. This does not convey a very magnificent idea of God, of spirits, and of the souls of men. I cannot conceive that my soul is nothing more than a being similar to the last particles of a body, or that it is reduced almost to a point. It appears to me still less capable of being maintained, that several souls joined together might form a body, a slip of paper, for example, to light a pipe of tobacco. But the supporters of this opinion go upon this ground, that as a spirit has no magnitude, it must, of necessity, resemble a geometrical point. Let us examine the solidity of their reasoning.

I remark, first, that as a spirit is a being of a nature totally different from that of body, it is absurd to apply to it standards, which suppose magnitude, and that, consequently, it would be folly to ask how many feet or inches long a spirit is, or how many pounds or ounces it weighs. These questions are applicable only to things which have length or weight, and are as absurd as if, speaking of time, it were to be asked, how many feet long an hour was, or how many pounds it weighed. I can always confidently affirm, that an hour is not equal to a line of a hundred feet, or of ten feet, or of one foot, or any other standard of measure; but it by no means follows that an hour must be a geometrical point. An hour is of a nature entirely different, and it is impossible to apply to it any standard which supposes a length which may be expressed by feet or inches.

The same thing holds good as to spirit. I can always boldly affirm, that a spirit is not ten feet, nor a hundred feet, nor any other number of feet; but it does not hence follow, that a spirit is a point, any more than that an hour must be one, because it cannot be measured by feet or inches. A spirit, then, is not a monad, or in any respect similar to the ultimate particles into which bodies may be divided; and you are perfectly able to comprehend, that a spirit may have no extension, without being, on that account, a point or a monad. We must therefore separate every idea of extension from that of spirit.

To ask, In what place does a spirit reside? would be, for the same reason, likewise an absurd question, for to connect spirit with place is to ascribe extension to it. No more can I say in what place an *hour* is; though assuredly an hour is something; something, therefore, may exist without being attached to a certain place. I can, in like manner, affirm that my soul does not reside in my head, nor out of my head, nor in any particular place, without its being deduced as a consequence that my soul has therefore no existence; just as it may be with truth affirmed of the hour now passing, that it exists neither in my head nor out of my head. A spirit exists, then, though not in a certain place; but if our reflection turns on the power which a spirit has of acting upon a body, the action is most undoubtedly performed in a certain place.

My soul, then, does not exist in a particular place,

but it acts there; and as God possesses the power of acting upon all bodies, it is in this respect we say He is everywhere, though his existence is attached to no place.

10th January, 1761.

LETTER XCIII.

The Subject continued. Reflections on the State of Souls after Death.

You will probably be surprised at the sentiment which I have just now ventured to advance, that spirits, in virtue of their nature, are in no place. In thus affirming, I shall perhaps be in danger of passing for a man who denies the existence of spirits, and consequently that of God. But I have already demonstrated, that something may exist, and have a reality, without being attached to any one place. The example drawn from an hour, though feeble, removes the greatest difficulties, though there is an infinite difference between an hour and a spirit.

The idea which I form of spirits appears to me incomparably more noble than that of those who consider them as geometrical points, and who reduce God himself to this class. What can be more shocking than to confound all spirits, and the Supreme Being among the rest, with the minutest particles into which a body is divisible, and to rank them in the same class with these particles, which it is not in the power of the learned term monad to ennoble!

To be in a certain place is an attribute belonging only to corporeal things; and as spirits are of a totally different nature, it is not a matter of surprise to say, that they are not to be found in any place; and I am under no apprehension of reproach for the elucidations which I have submitted to you on this subject. It is thus I exalt the nature of spirits infinitely above that of bodies.

Every spirit is a being that thinks, reflects, reasons, deliberates, acts freely, and, in one word, that lives: whereas body has no other qualities but that of being extended, susceptible of motion, and impenetrable; from whence results this universal quality, that every body remains in the same state as long as there is no necessity of mutual penetration, or of their undergoing some change; and in case of the necessity of their penetrating each other, if they continued to remain in their state, their impenetrability itself supplies the powers requisite to change their state, as far as it is necessary to prevent all penetration.

In this consist all the changes which take place in bodies: all is passive, and necessarily befalls them in conformity to the laws of motion. There is, in body, neither intelligence, nor will, nor liberty: these are the supereminent qualities of spirits, while bodies are not even susceptible of them.

It is spirit likewise which produces in the corporeal world the principal events, the illustrious actions of intelligent beings, which are all the effect of the influence which the souls of men exercise upon their bodies. This power, which every soul has over its body, cannot but be considered as a gift of God, who has established this wonderful union between soul and body. And as I find my soul in such a union with a certain particle of my body, concealed in the brain, it may be said that the seat of my soul is in that spot, though, properly speaking, my soul resides nowhere, and is referable to that place of my body only in virtue of its action and of its power.

It is also the influence of the soul upon the body which constitutes its life, which continues as long as this unison subsists, or as the organization of the body remains entire. Death, then, is nothing else but the dissolution of this union, and the soul has no need to be transported elsewhere; for, as it resides in no place, all places must be indifferent to it; and, consequently, if it should please God, after my death, to establish a new union between my soul and an organized body in the moon, I should instantly be in the moon, without the trouble of a long journey. And if, even now, God were to grant to my soul a power over an organized body in the moon, I should be equally here and in the moon; and this involves no manner of contradiction. It is body only which cannot be in two places at once; but there is nothing to prevent spirit, which has no relation to place, in virtue of its nature, to act at the same time on several bodies, situated in places very remote from each other; and in this respect it might be said, with truth, that it was in all these places at once.

This supplies us with a clear elucidation of the omnipresence of God: it is, that his power extends to the whole universe, and to all the bodies which it contains. It appears to me, of consequence, an improper expression, to say that God exists everywhere, as the existence of a spirit has no relation to place. It is more consonant with propriety to say, God is everywhere present.

Let us now compare this idea with that of the Wolffians, who, representing Deity under the idea of a point, attach Him to one fixed place, as, in fact, a point cannot be in several places at once; and how is it possible to reconcile the Divine omnipotence with the idea of a point?

Death being a dissolution of the union subsisting between the soul and body during life, we are enabled to form some idea of the state of the soul after death. As the soul, during life, derives all its knowledge through the medium of the senses, being deprived by death of the information communicated through the senses, it no longer knows what is passing in the material world; this state might, in some respects, be compared to that of a man who should all at once become blind, deaf, dumb, and deprived of the use of all the other senses. Such a man would retain the knowledge which he had acquired through the medium of sense, and might continue to reflect on ideas previously formed; his own actions especially might supply an ample store; and, finally, the faculty of reasoning might remain entire, as the body in no respect whatever contributes to its exercise.

Sleep likewise furnishes us with something like an example of this state, as the union between soul and body is then in a great measure interrupted; though the soul, even in sleep, ceases not from exerting its activity, being employed in the production of what we call dreams. These dreams are usually very much disturbed, by the remains of the influence which the senses still exercise over the soul; and we know by experience, that the more this influence is suspended, which is the case in very profound sleep, the more regular and connected likewise our dreams are. Thus, after death, we will find ourselves in a more perfect state of dreaming, which nothing shall be able to discompose; it shall consist of representations and reasonings perfectly well kept up. And this, in my opinion, is nearly all we can say of it, at least with any appearance of reason.

13th January, 1761.

LETTER XCIV.

Considerations on the Action of the Soul upon the Body, and of the Body upon the Soul.

As the soul is the principal part of our being, it is of high importance thoroughly to investigate its operations. You will please to recollect, that the union between the soul and the body contains a twofold influence; by the one, the soul perceives and feels all that passes in a certain part of the brain; and by the other, it has the power of acting on that same portion of the brain, and of producing certain motions in it.

Anatomists have taken infinite pains to discover this part of the brain, which is justly called the seat of the soul; not that the soul actually resides there, for it is not confined to any place, but because the power of acting is attached to that spot. It may be said, that the soul is present there; but not that it exists there, or that its existence is limited to it. This part of the brain is undoubtedly that in which all the nerves terminate; now, anatomists tell us that this termination is in a certain portion of the brain, which they term the *callous body*. This, therefore, we may consider as the seat of the soul; and the Creator has bestowed upon every soul such a power over this callous membrane of his body, that it not only perceives all that passes there, but is likewise able to produce a reciprocal impression. Here, then, we observe a twofold action: the one, by which the body acts upon the soul—and the other, by which the soul acts upon the body; but these actions are infinitely different from those which bodies exercise upon other bodies.

The soul, from its union with the *corpus callosum*, finds itself intimately connected with the whole body, by means of the nerves, which are thence universally diffused. Now, the nerves are fibres so wonderfully constructed, and to all appearance filled with a fluid so subtile, that the slightest change which they undergo at one extremity is instantly communicated to the other extremity in the brain, where the seat of the soul is. And, reciprocally, the slightest impression made by the soul on the extremities of the nerve, in the *corpus callosum*, is immediately trans-

mitted through the whole extent of every nerve; and it is thus that the muscles and members of our bodies are put in motion, and obey the commands of the soul.

This wonderful structure of the body places it in a very close connexion with all exterior objects, whether near or remote, which may act upon it, either by immediate contact, as in feeling and tasting, or by their exhalations, as in smelling. Bodies at a great distance act on the sense of hearing when they make a noise, and exert in the air vibrations which strike our ears; they act likewise upon the sight, when they are illumined, and transmit into our eyes the rays of light, which consist, in like manner, in a certain vibration caused in that medium much more subtile than the air, which we call *ether*. It is thus that bodies, both near and remote, may act upon the nerves of our body, and produce certain impressions in the *corpus callosum*, from which the soul derives its perceptions.

From every thing, therefore, which makes an impression on our nerves, there results a certain change in the brain, of which the soul has a perception, and thereby acquires the idea of the object which caused it. We have here, then, two things to be examined: the one is corporeal, or *material*, which is the impression, or the change produced in the *corpus callosum* of the brain; the other *spiritual*, namely, the perception, or the information, which the soul derives from it. It is, if I may so express myself, from the contemplation of what passes in the *corpus callosum*, that all our knowledge is derived.

You must permit me to enter into a more particular detail on this important article. Let us, first, consider one single sense, say that of smelling, which, being the least complicated, seems the most proper to assist us in our researches. Suppose all the other senses annihilated, and that a rose was applied to the nose; its exhalation would at once excite a certain agitation in the nerves of the nose, which thence transmitted to the *corpus callosum*, will occasion there likewise some change; and in this consists the *material* circumstance which is the subject of our investigation. This slight change, produced in the *corpus callosum*, is then perceived by the soul, and it thence acquires the idea of the smell of a rose; and this is the *spiritual* operation which takes place: but we cannot explain in what manner this is done, as it depends on the incomprehensible union which the Creator has established between the body and the soul.

It is certain, however, that upon this change in the *corpus callosum*, there is excited in the soul the idea of the smell of a rose, or the contemplation of this change furnishes to the soul a certain idea, that of the smell of a rose, but nothing more; for as the other senses are suspended, the soul can form no judgment of the nature of the object itself which suggested this idea—the idea of the smell of a rose alone was excited in the soul. Hence we comprehend that the soul does not form this idea of itself, for it would have remained unknown but for the presence of a rose. But further, the soul is not indifferent with respect to it; the perception of this idea is agreeable; the soul itself is somehow interested in it. Accordingly, we say that the soul feels the odour of the rose; and this perception we call *sensation*.

It is the same with all the other senses; every object by which they are struck excites in the *corpus callosum* a certain change, which the soul observes with a sensation agreeable or disagreeable, and from which it derives the idea of the object which caused it. This idea is accompanied with a sensation so much the stronger and more intense, as the impression made on the *corpus callosum* is more lively. It is thus that the soul, by contemplating the changes produced in the *corpus callosum* of the brain, acquires ideas, and is affected by them; and this is what we understand by the term *sensation.*[*]

17*th January*, 1761.

LETTER XCV.

Of the Faculties of the Soul, and of Judgment.

Had we no other sense but that of smelling, our knowledge would be very limited; we should then have no other sensation than that of odours, the diversity of which, were it ever so great, could not very much interest our soul; being restricted to this, that agreeable smells would procure some degree of pleasure, and such as are disagreeable would excite some disgust.

But this very circumstance carries us forward to a most important inquiry: Whence is it that one smell is agreeable, and another disgusting? It cannot be a matter of doubt, that agreeable smells excite in the *corpus callosum* a different agitation from that which is produced by the disagreeable; but how comes it, that one agitation in the *corpus callosum* can give pleasure to the soul, while another is offensive, and even frequently becomes insupportable? The cause of this difference resides no longer in body and matter; we must look for it in the nature of the soul itself, which enjoys a certain pleasure in feeling certain agitations, while others excite uneasiness; and the real cause of this effect we do not know.

Hence we comprehend that the soul does more than simply perceive what passes in the brain, or *corpus callosum*; it subjoins to sensation a judgment respecting what it finds agreeable or disgusting, and consequently exercises, besides the faculty of perceiving, another and a different faculty, that of judging; and this judgment is wholly different from the simple idea of a smell.

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[*] There are probably very few scientific anatomists of the present day who would consider the statements in this and succeeding Letters relative to the *corpus callosum* as worthy of much confidence.—*Am. Ed.*

The same consideration, of the sense of smelling only, discovers to us still other acts of the soul. When the smells are changed, when you apply to the nose a carnation after a rose, the soul has not only a perception of both smells, but likewise remarks a difference between them. Hence we conclude, that the soul still retains the preceding idea to compare it with that which follows; in this consists *reminiscence*, or memory, by which we have the power of recalling ideas, antecedent and past. Now the real source of memory is entirely concealed from us. We know well that the body has much to do in it; for experience assures us, that disease, and various accidents which befall the body, weaken and frequently destroy the memory: it is equally certain, at the same time, that the recollection of ideas is the proper work of the soul. A recollected idea is essentially different from an idea excited by an object. I have a perfect recollection of the sun which I saw to-day; but this idea greatly differs from that which I had while I was looking at the sun.

Some authors pretend, that when we recall an idea, there happens in the brain an agitation similar to that which first produced it; but if this were the case, I should actually see the sun; it would no longer be a recollected idea. They admit, indeed, that the agitation which accompanies the recalled idea is much weaker than that from which the original idea proceeded: but still I am not satisfied with this; for it would thence follow, that when I recall the idea of the sun, it would be much the same as when I see the moon, the light of which, you will please to remember, is about 200,000 times weaker than that of the sun. But actually to look at the moon, and simply to recollect the sun, are two things absolutely different.

We may say with truth, that the recollected ideas are the same with the actual ideas; but this identity respects only the soul; with regard to the body, the actual idea is accompanied with a certain agitation in the brain, whereas the recollected one is destitute of it. Accordingly, we say that the idea which I feel, or which an object acting on my senses excites in my soul, is a sensation; but it can with no propriety be said that a recollected idea is a sensation. To recollect and to feel always remain two things absolutely different.

When, therefore, the soul compares two different smells, when it has the idea of the one from the presence of an object acting on the sense of smelling, and that of the other from recollection, it has in fact two ideas at once, the actual idea and the recollected idea; and in pronouncing whether of the two is more or less agreeable or disagreeable, it exerts a particular faculty, distinct from that by which it only contemplates what is presented to it.

But the soul performs still other operations, when a succession of several different smells is presented to it; for while it is struck with each of these in its turn, the preceding are recollected, and a notion is thereby acquired of past and present, and even of future, when new sensations are proposed, similar to those of which it has already had experience. It thence likewise derives the idea of succession, in as much as it undergoes several impressions successively; and hence results the idea of *duration*, and of *time*. Finally, on remarking the diversity of sensations which succeed each other, it begins to reckon *one*, *two*, *three*, &c., though this should not go farther, from want of signs or names wherewith to mark numbers. For supposing a man has just begun to exist, and who has hitherto experienced no sensations but those of which I have been speaking, far from having created a language for himself, he only knows how to exert his first faculties on the simple ideas which the sense of smelling presents to him.

You see, then, that the man in question has already acquired the capacity of forming to himself ideas of diversity of the present, of the past, and even of the future; afterward, of succession, of the duration of time, and of number, or at least of the elements of these ideas. Some authors pretend, that such a man could not acquire the idea of the duration of time without a succession of different sensations; but it appears to me that the same sensation, the smell of the rose, for example, being continued for a considerable time together, he would be differently affected by it than he would if it were presently withdrawn. A very long duration of the same sensation would at length become tiresome, which would necessarily excite in him the idea of duration. It must certainly be allowed, that his soul would be sensible of a very different effect if the sensation were continued long, than if it lasted only for a moment; and the soul will clearly perceive this difference: it will accordingly have some idea of duration and of time, without any variation of the sensations.

These reflections which the soul makes, occasioned by its sensations, are what properly belong to its *spirituality*, the body furnishing only simple sensations. The perception of these sensations is already an act of the soul's spirituality; for a body can never acquire ideas.

20th January, 1761.

LETTER XCVI.

Conviction of the Existence of what we perceive by the Senses. Of the Idealists, Egotists, and Materialists.

In all the sensations which we experience when one of our senses is struck by any object, it is a matter of high importance to remark, that the soul not only acquires an idea conformed to the impression made on the nerves, but that it judges, at the same time, there must exist an exterior object, which furnished this idea. Though habit makes us consider this judgment as extremely natural, yet we have reason to be astonished at it, when we examine more attentively what then passes in our brain.

An example will place this in a clear light. I shall suppose you looking at the full moon by night; the rays which enter into your eyes will at once paint on the retina an image similar to the moon, for the minute particles of the retina are by the rays put into a vibration similar to that which agitates those of the moon. Now the retina being only a contexture of nerves extremely subtile, you easily comprehend that these nerves must hence undergo a certain agitation, which will be transmitted to the origin of the nerves in the brain. There will be excited, therefore, likewise in that portion of the brain a certain agitation, which is the real object that the soul contemplates, and from which it derives an article of knowledge, which is the idea of the moon. Consequently, the idea of the moon is nothing else but the contemplation of this slight agitation affecting the origin of the nerves.

The activity of the soul is so much attached to the spot in which the nerves terminate, that it absolutely knows nothing of the images painted on the bottom of the eye, and still less of the moon, whose rays have formed these images. The soul, however, does not satisfy itself with the mere speculation of the agitation in the brain, which supplies it immediately with the idea of the moon; it subjoins to this the judgment, that there really exists out of us an object which we call the moon. This judgment is reduced to the following reasoning:

There has taken place in my brain a certain agitation, a certain impression; I do not absolutely know by what cause it has been produced, as I know nothing even of the images which are the immediate cause of it upon the retina; nevertheless, I boldly pronounce that there is a body out of me, the moon, which supplied me with this sensation.

What a consequence! May it not be more probable that this agitation, or this impression, is produced in my brain by some internal cause, such as the motion of the blood, or perhaps merely by chance? What right have I, then, to conclude that the moon actually exists? If I conclude from it, that there is at the bottom of my eye a certain image, this might pass; as, in fact, this image is the immediate cause of the impression made on the brain; though it was sufficiently bold to hazard even this conclusion. But I go much farther, and because there is a certain agitation in my brain, I proceed to conclude, that there exists, out of my body, nay, in the heavens, a body, which is the first cause of such impression, and that this body is the moon.

In sleep, when we imagine we see the moon, the soul acquires the same idea; and perhaps a similar agitation is then produced in the brain, as the soul imagines that it then really sees the moon. It is undoubtedly certain, that in this we deceive ourselves; but what assurance have we that our judgment is better founded when we are awake? Philosophers have lost their way more than once in endeavouring to solve this difficulty.

What I have just said respecting the moon takes place with regard to all the bodies which we see. The consequence is not apparent, that there must exist bodies out of us, because our brain undergoes certain agitations or impressions. This applies even to our own limbs, and to our whole body, of which we know nothing but by means of the senses, and of the impressions which they make in the brain; if, then, these impressions, and the ideas which the soul derives from them, prove nothing as to the existence of body, that of our own body becomes equally doubtful.

You will not therefore be surprised, that there should be philosophers who have openly denied the existence of bodies; and in truth it is not easy to refute them. They derive a very strong argument from dreams, in which we imagine that we see so many bodies which have no existence. It is said with truth, that then it is pure illusion; but what assurance have we that we are not under the power of a similar illusion when awake? According to these philosophers, it is not an illusion: the soul, they admit, perceives a certain impression—an idea; but they boldly deny it to be a consequence, that bodies really exist which correspond to those ideas. The supporters of this system are called *idealists*, because they admit the *ideas* only of material things, and absolutely deny their existence. They may likewise be denominated *spiritualists*, as they maintain that no beings exist except spirits.

And as we do not know other spirits but by means of the senses, or of ideas, there are philosophers who go so far as to deny the existence of all spirits, their own soul excepted, of the existence of which every one is completely convinced. These are called *egotists*, because they pretend that nothing exists but their own soul.

To them are opposed the philosophers whom we denominate *materialists*, who deny the existence of spirits, and maintain that every thing which exists is matter, and that what we call our soul is only matter extremely subtile, and thereby rendered capable of thought.

24th January, 1761.

LETTER XCVII.

Refutation of the Idealists.

I WISH it were in my power to furnish you with the arms necessary to combat the idealists and the egotists, by demonstrating, that there is a real connexion between our sensations and the objects themselves which they represent; but the more I think of it, the more I feel my own incapacity.

It would be ridiculous to think of engaging with the egotists; for a man who imagines he alone exists, and who does not believe in my existence, would act in contradiction to his own system if he paid any attention to my reasoning, which, according to him, would be that of an imaginary being. It is likewise a hard task to confute the idealists—nay, it is impossible to convince of the existence of bodies a man obstinately determined to deny it. Though no such philosophers existed, it would be highly interesting to be able to convince ourselves, that as often as our soul experiences sensations, it may be with certainty concluded that bodies likewise exist; and that, when my soul is affected by the sensation of the moon, I may thence boldly infer the existence of the moon.

But the union which the Creator has established between the soul and the brain is a mystery so unfathomable, that all our knowledge of it amounts only to this: certain impressions made in the brain, where the seat of the soul is, excite in it certain ideas or sensations; but the cause of this influence is absolutely unknown to us. We ought to satisfy ourselves with knowing that this influence subsists, which experience sufficiently confirms; and it is in vain to investigate *how* this is produced. Now, the same experience which proves it informs us likewise that every sensation always disposes the soul to believe that there exists, out of it, some object which excited such sensation; and that sensation discovers to us several properties of the object.

It is, then, a most undoubted fact, that the soul always concludes, from any sensation whatever, the existence of a real object out of us. This is so natural to us from our earliest infancy, and so universally the case with all men, and even with animals, that it cannot with any propriety be called a prejudice. The dog that barks when he sees me is certainly convinced that I exist; for my presence excites in him the idea of my person. The dog, then, is not an idealist. Even the meanest insects are assured that bodies exist out of them; and they could not have this conviction but by the sensations excited in their souls.

I believe, therefore, that sensations include much more than those philosophers are disposed to admit. They are not only simple perceptions of certain impressions made in the brain; they supply the soul not with ideas only, but they effectively represent to it objects externally existing, though we cannot comprehend how this is done.

In fact, what resemblance can there be between the luminous idea of the moon, and the slight impression which its rays may produce in the brain by means of nerves?

The idea, even in as far as the soul perceives it, has nothing material; it is an act of the soul, which is a spirit: it is not necessary, therefore, to look for a real relation between the impressions of the brain and the ideas of the soul; it is enough for us to know that certain impressions made in the brain excite certain ideas in the soul, and that these ideas are representations of objects externally existing, of whose existence they give us the assurance.

Thus, when my brain excites in my soul the sensation of a tree, or of a house, I pronounce, without hesitation, that a tree, or a house, really exists out of me, of which I know the place, the size, and other properties. Accordingly, we find neither man nor beast who calls this truth in question. If a clown should take it into his head to conceive such a doubt, and should say, for example, he does not believe that his bailiff exists, though he stands in his presence, he would be taken for a madman, and with good reason; but when a philosopher advances such sentiments, he expects we should admire his knowledge and sagacity, which infinitely surpass the apprehensions of the vulgar.

It appears to me, accordingly, abundantly certain that such extravagant sentiments would never have been maintained, but from pride and an affectation of singularity; and you will readily believe that the common people have, in this respect, much more good sense than those learned gentlemen who derive no other advantage from their researches but that of bewildering themselves in a labyrinth of chimeras, unintelligible to the rest of mankind.

Let it be established, then, as a certain rule, that every sensation not only excites in the soul an idea, but shows it, if I may so express myself, an external object, of whose existence it gives full assurance without practising a deception. A very formidable objection, however, is started against this, arising from dreams and the reveries of sick persons, in which the soul experiences a great variety of sensations of objects which nowhere exist. The only reflection I shall suggest on this subject is, that it must be very natural for us to judge that the objects, the sensation of which the soul experiences, really exist, as we judge after this manner even in sleep, though then we deceive ourselves; but it does not thence follow that we likewise deceive ourselves when we are awake. In order to remove this objection, it is necessary to know better the difference of the state of the man who is asleep and of him who wakes; and none, perhaps, know this less than the learned, which must surely be a matter of some surprise to you.

27th January, 1761.

LETTER XCVIII.

The Faculty of Perceiving. Reminiscence, Memory, and Attention. Simple and compound Ideas.

You are by this time sensible that objects by acting upon our senses excite in the soul sensations, from which we judge that they really exist out of us. Though the impressions which occasion these sensations are made in the brain, they present, then, to the soul a species of image similar to the object which the soul perceives, and which is called the *sensible idea*, because it is excited by the senses. Thus, on seeing a dog the soul acquires the idea of it; and it is by means of the senses that the soul comes to the knowledge of external objects, and acquires sensible ideas of them, which are the foundation of all our attainments in knowledge.

This faculty of the soul, by which it acquires the knowledge of external things, is denominated the *faculty of perception*, and depends, no doubt, on the wonderful union which the Creator has established between the soul and the brain. Now the soul has still another faculty, that of recalling ideas already communicated by the senses; and this faculty is named *reminiscence*, or *imagination*. Thus, having

once seen an elephant, you will be able to recollect the idea of that animal, though it is no longer before you. There is, however, a mighty difference between actual and recollected ideas: the former make an impression much more lively and interesting than the latter; but the faculty of recalling ideas is the principal source of all our knowledge.

Did we lose the ideas of objects as soon as they cease to act upon our senses, we should never be able to make any reflection, any comparison; and our knowledge would be entirely confined to the things which we should feel at the moment, all preceding ideas being extinguished, as if we had never possessed them.

It is, therefore, a faculty essential to reasonable beings, and with which animals too are endowed, that of being able to recollect past ideas. You know the faculty of which I speak is *memory*. It by no means follows, however, that we have it always in our power to recall all our past ideas. How frequently do we exert ourselves in vain to recollect certain ideas which we formerly had! Sometimes we forget them entirely; but for the most part only partially.

If you should happen, for example, to forget the demonstration of the Pythagorean theorem, with all your efforts, perhaps, you should not be able to recollect it—but this would be only a partial forgetfulness; for as soon as I had again drawn the figure, and put you in the train of the demonstration, you will presently recollect it; and this second demonstration will make on your mind quite a different impression from the first. We see, then, that the reminiscence of ideas is not always in our power, though they may not be wholly extinguished; and a slight circumstance is frequently capable of reproducing them.

We must therefore carefully distinguish between sensible and recollected ideas. Sensible ideas are represented to us by the senses; but we ourselves form recollected ideas on the model of the sensible, as far as we remember them.

The doctrine of ideas is of the last importance for the purpose of a thorough disquisition of the real sources of human knowledge. And, first, ideas are distinguished into *simple* and *complex*. A simple idea is that in which the soul finds nothing to distinguish, and remarks no parts different from each other. Such is, for example, the idea of a smell, or of a spot on a substance of one colour; such is likewise that of a star, in which we perceive only one luminous point. A complex idea is a representation in which the soul is able to distinguish several different things. When, for instance, we look attentively at the moon, we discover several dark spots, surrounded by contours more luminous; we remark also her round figure when she is full, and her horned figure when waxing or waning. On viewing her through the telescope, there are many other particulars distinguishable.

How many different things do we not perceive in beholding a noble palace, or a fine garden? When you do me the honour to read this Letter, you will discover in it the different traits of the characters, which you can with ease distinguish from each other. This, then, is a complex idea, as it contains a variety of simple ideas. Not only this Letter, taken in whole, presents a complex idea, from its consisting of a plurality of words; but every word too is a complex idea, being composed of several characters; nay, every character is one, from the singularity of the form which distinguishes it from others; but the elements or points which constitute every character may be considered as simple ideas, inasmuch as you no longer perceive in them any diversity. A greater degree of attention will likewise discover some variety in these elements, on viewing them through a microscope.

There is a great difference, therefore, even in the manner of contemplating objects. When we observe them only slightly and transiently, we perceive very little variety; but to an attentive consideration, every particular detail stands disclosed. A savage, on throwing his eyes over this Letter, will take it for a piece of paper scribbled all over, and will distinguish only the black from the white, whereas an attentive reader observes in it the peculiar form of every character. Here, then, we have a new faculty of the soul, denominated *attention*, by which it acquires the simple ideas of the different things that meet in one object.

Attention requires address, the result of long and frequent exercise, to render it capable of distinguishing the different parts of an object. A clown and an architect, passing by a palace, will both receive the impression of the rays which enter into their eyes; but the architect will discover a thousand minute particulars of which the clown has no perception. Attention alone produces this difference.

31*st January*, 1761.

LETTER XCIX.

Division of Ideas into clear and obscure, distinct and confused. Of Distraction.

If we consider, in a slight manner only, a representation made to us by the senses, the idea which we acquire from it is very imperfect, and we say it is *obscure;* but the more attention that we employ to distinguish all its parts, the more *perfect* or *distinct* our idea will become. In order to acquire a perfect or distinct idea of an object, it is not then sufficient that it should be represented in the brain by impressions made upon the senses—the soul too must apply its attention, which is properly an act of the soul, independent upon the body.

It is further necessary that the representation in the brain should be well expressed, and contain the different parts and qualities which characterize the object. This takes place when the object is presented to the senses in a suitable manner. When, for example, I see a piece of writing at the distance of ten feet, I am unable to read it, let me employ whatever degree of attention I may; the distance of the characters prevents their being accurately expressed on the bottom of the eye, and consequently also in the brain: but if the same writing is brought to a proper distance, I can read it, because then all the characters are distinctly represented on the bottom of the eye.

You know that we employ certain instruments in order to procure a more perfect representation in the organs of sense, such as microscopes and telescopes; which are intended as supplements to the imperfection of vision. But, in employing their assistance, we are incapable of attaining a distinct idea without attention; otherwise we acquire but an obscure idea, nearly such as we should have had by taking a glimpse of the object only.

I have already remarked, that sensations are by no means indifferent to the soul, but agreeable or disagreeable; and this agreeableness, or its opposite, excites our attention, unless the soul is pre-occupied by several other sensations which entirely engross it: this last state of the soul is termed *distraction*.

Exercise likewise greatly contributes to strengthen attention: and there cannot be a mode of exercise more suitable to children than teaching them to read; for they are thereby laid under the necessity of fixing their attention successively on every character, and of impressing on their minds a clear idea of the figure of each. It is easy to see that this exercise must be at first extremely painful; but such a habit is so speedily acquired, that even a child, after a little application, can read with astonishing quickness. In reading a piece of writing, we must have a very distinct idea of every character; thus attention is susceptible of a very high degree of perfection from exercise.

With what amazing rapidity will a proficient in music execute the most difficult piece, though he never saw it before! It is certain that his attention must have run over all the notes, one after another, and that he remarked the signification of each. His attention, however, is not confined only to these notes; it presides likewise over the motion of the fingers, not one of which moves but by an express order of the soul; he remarks likewise, at the same time, how the other performers execute their parts. It is, upon the whole, altogether surprising to what a height the address of the human mind may be carried by application and exercise. Show the same piece of music to a beginner; how much time does it require to impress on his mind the signification of every note, and to give him a complete idea of it: while the master acquires it by almost a single glance.

This ability extends equally to all other kinds of objects, in which one man may infinitely surpass another. There are persons who, with one glance fixed on a person passing before them, acquire a distinct idea, not only of all the features of the face, but the particulars of his whole dress, down to the minutest trifles, while others are incapable of remarking the most striking circumstances.

We observe, in this respect, an infinite difference among men. Some promptly catch all the different marks of an object, and form to themselves a distinct idea of it, while that formed by others is extremely obscure. This difference depends, not only on mental penetration, but likewise on the nature of the objects. A musician catches at once the whole piece of music, and acquires a distinct idea of it; but present him with a piece of writing in Chinese characters, and he will have only very obscure ideas indeed of such writing: the Chinese, on the contrary, will know at first sight the real import of each character, but will, in his turn, understand nothing of musical notes. The botanist observes in a plant which he never saw before a thousand particulars which escape the attention of another; and the architect discerns, by a single glance, in a building, many things which another, with a much greater degree of attention, could not have discovered.

It is always useful to form distinct ideas of the objects presented to our senses; in other words, to remark all the parts of which they are composed, and the marks which distinguish and characterize them. From these observations you will easily comprehend the division of ideas into obscure and clear, into confused and distinct. The more distinct they are, the more they contribute to the advancement of knowledge.

3d February, 1761.

LETTER C.

Of the Abstraction of Notions. Notions general and individual. Of Genus and Species.

The senses represent objects only which exist externally; and sensible ideas all refer to them: but of these sensible ideas the soul forms to itself a variety of other ideas, which are indeed derived from these, but which no longer represent objects really existing.

When, for example, I look at the full moon, and fix my attention only on its contour, I form the idea of roundness; but I cannot affirm that roundness exists of itself. The moon is round, but the round figure does not exist separately out of the moon. It is the same with respect to all other figures; and when I see a triangular, or square table, I may have the idea of a triangle, or of a square, though such a figure exists nowhere of itself, or separately from an object possessing that figure.

The ideas of numbers have the same origin. Having seen two or three persons, the soul forms the idea of two or three, without attaching it any longer to the persons. Having already acquired the idea of *three*, the soul is able to proceed, and to form the ideas of greater numbers, of four, five, ten, a hundred, a thousand, and so on, without ever having precisely seen so many things together. A single instance, therefore, in which we have seen two or three objects, may carry the soul forward to the formation of the ideas of other numbers, be they ever so great.

The same thing holds as to figures; and you have the power of forming to yourself the idea of a polygon, with 1761 sides, for example, though you never have seen an object of that form, and though no one such, perhaps, ever existed.

Here the soul exerts a new faculty, which is called the power of *abstraction;* this takes place when the soul fixes its attention on only one quantity or quality of the object, and considers it separately, as if it were no longer attached to the object. When, for instance, I put my hand on a heated stone, and confine my attention to the heat only, I form from it the idea of heat, which is no longer attached to the stone. This idea of heat is formed by abstraction, as it is separated from the stone; and the soul might have derived the same idea from touching a piece of wood heated, or by plunging the hand into hot water.

Thus, by means of abstraction, the soul forms a thousand other ideas of the quantities and properties of objects, by separating them afterward from the objects themselves: as, when I see a red coat, and fix my attention only on the colour, I form the idea of red, separate from the coat; and it is obvious that a red flower, or any other substance of that colour, would have enabled me to form the same idea.

These ideas, acquired by abstraction, are denominated *notions*, to distinguish them from sensible ideas, which represent to us objects really existing.

It is alleged that the power of abstraction is a prerogative of men, and of other rational beings, and that the beasts are entirely destitute of it. A beast may experience the same sensation of hot water that we do, but is unable to separate the idea of heat and that of the water itself: it knows heat only in so far as it is connected with the water, but has not the abstract idea of heat which we have. It is said that these notions are general ideas, which extend to several things at once, as we may find heat in stone, wood, water, or any other body; but our idea of heat is not attached to any one body; for if my idea of heat were attached to a certain stone, which first supplied me with that idea, I could not affirm that wood or other bodies were hot. Hence it is evident, that these notions, or general ideas, are not attached to certain objects, as sensible ideas are; and as they distinguish man from the brute creation, they properly exalt him to a degree of rationality wholly unattainable by the beasts.

There is still further a species of notions, likewise formed by abstraction, which supply the soul with the most important subjects on which to employ its powers: these are the ideas of *genus* and *species*. When I see a pear-tree, a cherry-tree, an apple-tree, an oak, a fir, &c., all these ideas are different; I nevertheless remark in them several things which they have in common; as the trunk, the branches, and the roots; I stop short only at those things which the different ideas have in common, and the object in which all such qualities meet I call a *tree*. Thus the idea of tree which I have formed in this manner is a *general notion*, and comprehends the sensible

ideas of the pear-tree, the apple-tree, and, in general, of every tree that exists.

Now, *the tree* which corresponds to my idea of tree nowhere exists; it is not the pear-tree, for then the apple would not be comprehended under it; for the same reason, it is not the cherry-tree, nor the plum, nor the oak, &c.; in a word, it exists only in my soul; it is only an idea, but which is realized in an infinite number of objects. In like manner, when I speak of a *cherry-tree*, it too is a general notion, which comprehends all the cherry-trees that exist: this notion is not restricted to a particular cherry-tree in my garden: for then every other cherry-tree would be excluded.

With respect to general notions, every existing object, comprehended under one, is denominated an *individual*, and the general idea, say that of the cherry-tree, is denominated *species* or *genus*. These two words signify nearly the same thing, but genus is the more comprehensive, including in it a variety of species. Thus the notion of a tree may be considered as a genus, as it includes the notions of pear-trees, apple-trees, oaks, firs, and so on, which are species; and of so many others, each of which contains a great number of existing individuals.

This manner of forming general ideas is, therefore, likewise performed by abstraction; and it is here chiefly that the soul exerts the activity and performs the operations from which all our knowledge is derived. Without these general notions, we should differ nothing from the brutes.

7th February, 1761.

LETTER CI.

Of Language; its Nature, Advantages, and Necessity, in order to the Communication of Thought, and the Cultivation of Knowledge.

WHATEVER aptitude a man may have to exercise the power of abstraction, and to furnish himself with general ideas, he can make no considerable progress without the aid of language, spoken or written. Both the one and the other contain a variety of words, which are only certain signs corresponding to our ideas, and whose signification is settled by custom, or the tacit consent of several men who live together.

It would appear from this, that the only purpose of language to mankind is mutually to communicate their sentiments, and that a solitary man might do very well without it; but a little reflection only is necessary to be convinced, that men stand in need of language, as much to pursue and cultivate their own thoughts as to keep up a communication with others.

To prove this, I remark, first, that we have scarcely a word in any language whose signification is attached to one individual object. If each cherry-tree in a whole country had its proper name, as well as every pear-tree, and, in general, every individual tree; what an enormous complication in language would result from it! Were I under the necessity of employing a particular term to denote every sheet of paper in my bureau, or if I should, from caprice, think fit to give each a particular name, this would be as useless to myself as to others.

It is, then, a very imperfect description of language to say, that men have, from the first, imposed on all individual objects certain names to serve them for signs. The words of a language express general notions; and you will rarely find one which marks only a single individual. The name *Alexander the Great* is applicable to one particular person; but then it is a compound name. There may have been many thousands of Alexanders; and the epithet *great* extends to an infinite number of things. It is thus that all men bear names, to distinguish them from others, though these names may be frequently common to many.

The essence of a language consists rather in its containing words to denote general notions, as that of tree corresponds to a prodigious number of individual beings. These words serve not only to convey to others, who understand the same language, the same idea which I affix to the words; but they are likewise a great assistance to me in representing this idea to myself. Without the word tree, which represents to me the general notion of a tree, I must imagine to myself at once a cherry-tree, a pear-tree, an apple-tree, a fir, &c., and thence extract what they have in common. This would necessarily oppress the mind, and speedily involve it in the greatest perplexity. But having, once for all, determined to express by the term tree the general notion formed by abstraction, this term always excites in my soul the same notion, without my having occasion to recollect its origin; and accordingly, the word *tree* alone, for the most part, constitutes the object of the soul, without the representation of any real tree.

The word *man* is, in like manner, a sign to denote the general notion of what all men have in common; and it would be very difficult to tell or to make the enumeration of all that this notion contains. Would you say that he is a living two-legged being? A cock would likewise be included in this description. Would you say, in words of Plato's definition, that he is a two-legged animal without feathers? You have only to strip the cock of his feathers, in order to obtain the Platonic man.

I do not know whether those who say that man is an animal endowed with reason, express themselves more accurately; for how often do we take for men certain beings of whose rationality we have no assurance. On viewing an army, I have not the least doubt that every soldier is a man, though I have not the smallest proof that they are all endowed with reason. If I were to make an enumeration of all the members necessary to constitute a man, some men would always be found defective in one, perhaps in several of these, or we might find some beast who had them all. On investigating, therefore, the origin of the general notion of man, it is almost impossible to say wherein it consists.

No one, however, has any doubt respecting the signification of the word; because every one, wishing to excite this notion in his soul, has only to think on the word *man*, as if he saw it written on paper, or heard it pronounced, according as the respective language of any one may be.

Hence we see that, for the most part, the objects of our thoughts are not so much the things themselves, as the words by which these things are denoted in language; which greatly facilitates the exercise of thought. What idea, in fact, do we associate with the terms *virtue*, *liberty*, *goodness*, &c.? Not surely a sensible image; but the soul, having once formed the abstract notions which correspond to these terms, afterward substitutes them in its thoughts, in place of the things which they denote.

You may easily conceive how many abstractions it was necessary to make, in order to arrive at the notion of *virtue*. The actions of men were first to be considered; they were then to be compared with the duties imposed on them; in consequence of this, we give the name of *virtue* to the disposition which a man has to regulate his actions conformably to his

duties. But, on hearing the word *virtue* rapidly pronounced in conversation, do we always connect with it this complex notion? And what idea is excited in the mind on hearing the particle *and* or *also* pronounced? It is readily seen that these words import a species of connexion; but take what pains you please to describe this connexion, you will find yourself under the necessity of employing other words, whose signification it would be equally difficult to explain; and if I were to attempt an explanation of the import of the particle *and*, I must make frequent use of that very particle.

You are now enabled to judge of what advantage language is to direct our thoughts; and that without language we should hardly be in a condition to think at all.

10th February, 1761.

LETTER CII.

Of the Perfections of a Language. Judgments and Nature of Propositions, affirmative and negative; universal or particular.

I HAVE been endeavouring to show you how necessary language is to man, not only for the mutual communication of sentiment and thought, but likewise for the improvement of the mind and the extension of knowledge.

These signs or words represent, then, general notions, each of which is applicable to an infinite number of objects: as, for instance, the idea of hot, and of heat, to every individual object which is hot; and the idea or general notion of *tree* is applicable to every individual tree in a garden or a forest, whether cherries, pears, oaks, or firs, &c.

Hence you must be sensible how one language may be more perfect than another. A language

always is so in proportion as it is in a condition to express a greater number of general notions, formed by abstraction. It is with respect to these notions that we must estimate the perfection of a language.

Formerly, there was no word in the Russian language to express what we call *justice*. This was certainly a very great defect, as the idea of justice is of very great importance in a great number of our judgments and reasonings, and as it is scarcely possible to think of the thing itself without a term expressive of it. They have accordingly supplied this defect by introducing into that language a word which conveys the notion of justice.

These general notions, formed by abstraction, are the source of all our judgments and of all our reasonings. A *judgment* is nothing else but the affirmation, or negation, that a notion is applicable, or inapplicable; and when such judgment is expressed in words, we call it a *proposition*. To give an example: *All men are mortal*, is a proposition which contains two notions; the first, that of men in general—and the second, that of mortality, which comprehends whatever is mortal. The judgment consists in pronouncing and affirming *that the notion of mortality is applicable to all men*. This is a judgment, and being expressed in words, it is a proposition; and because it affirms, we call it *an affirmative proposition*. If it denied, we would call it *negative*, such as this, *No man is righteous*. These two *propositions*, which I have introduced as examples, are *universal*, because the one affirms of *all* men that they are mortal, and the other denies that they are righteous.

There are likewise *particular propositions*, both negative and affirmative; as *Some men are learned*, and *Some men are not wise*. What is here affirmed, and denied, is not applicable to all men, but to *some* of them.

Hence we derive four species of propositions.

The first is that of *affirmative and universal propositions*, the form of which in general is:

Every A is B.

The second species contains *negative and universal propositions*, the form of which in general is:

No A is B.

The third is that of *affirmative propositions*, but *particular*, contained in this form:

Some A is B.

And, finally, the fourth is that of *negative* and *particular propositions*, of which the form is:

Some A is not B.

All these propositions contain essentially two notions, A and B, which are called the *terms of the proposition:* the first of which affirms or denies something,—and this we call the *subject:* and the second, which we say is applicable, or inapplicable, to the first, is the *attribute*. Thus, in the proposition, *all men are mortal*, the word *man*, or *men*, is the subject, and the word *mortal* the attribute: these words are much used in logic, which teaches the rules of just reasoning.

These four species of propositions may likewise be represented by figures, so as to exhibit their nature to the eye. This must be a great assistance towards comprehending more distinctly wherein the accuracy of a chain of reasoning consists.

As a general notion contains an infinite number of individual objects, we may consider it as a space in which they are all contained. Thus, for the notion of *man* we form a space, *Fig*. 41, in which we conceive all men to be comprehended. For the notion of *mortal* we form another, *Fig*. 42, in which we conceive every thing mortal to be comprehended. And when I affirm *all men are mortal*, it is the same thing with affirming that the first figure is contained in the second.

Fig. 41.

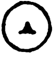
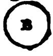


Fig. 42.



is the *attribute*.

II. As to negative univers
tions, the two spaces A and
A always denotes the *subj*
the *attribute*, will be represe
Fig. 44, the one separated
other; because we say *no*
that nothing comprehended
notion B.

III. In affirmative partic
tions, as, *some A is B*, a par
A will be comprehended in
Fig. 45; as we see here, t
comprehended in the notio

IV. For negative partic
tions, as, *some A is not B*,
space A must be out of t
Fig. 46. This figure resem
ceding; but we here remar
that there is something in
which is not comprehended
is out of it.

14th February, 1761.

to explain; whereas by means of these signs the whole is rendered sensible to the eye. We may employ, then, spaces formed at pleasure to represent every general notion, and mark the subject of a proposition by a space containing A, and the attribute by another which contains B. The nature of the proposition itself always imports, either that the space of A is wholly contained in the space B, or that it is partly contained in that space; or that a part, at least, is out of the space B; or, finally, that the space A is wholly out of B.*

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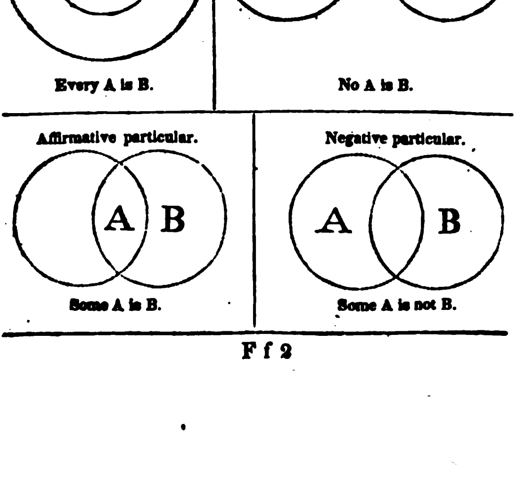
* Our author subjoins here the following diagram, with this short introduction:—"I shall once more give you a visible representation of these figures or emblems of the four species of propositions."

Emblems of the four Species of Propositions.



notion A may contain the no
tirely, as in *Fig.* 47; and t
same time, as is clear from t
part of the space A may be in
B, and that a part of A may n
Now, if A were, for example,
tree in general, and B that of
is contained wholly in the firs
sitions might be formed:

I. All oaks are
II. Some trees a
III. Some trees a

In like manner, if of two s
out of the other, as in *Fig.* 44
A is B, as *no B is A;* as if I w
a tree, and no tree is a man.

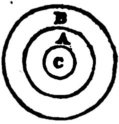
In the third case, where th
part in common, as in *Fig.* 45,

I. Some A is
II. Some B is
III. Some A is
IV. Some B is

This may suffice to show you
may be represented by figure
utility is manifest in reasonin
pressed in words, are called *syl*
the object is to draw a just con
given propositions

I. If the notion C is entirely contained in the notion A, it will be so likewise in the notion B, *Fig* 48; hence results this form of syllogism.

Fig. 48.



Every A is B:
But Every C is A:
Therefore Every C is B.

Which is the conclusion.

Let the notion A, for example, comprehend all trees, the notion B every thing that has roots; and the notion C all oaks, and then our syllogism will run thus:

Every tree has roots:
But Every oak is a tree:
Therefore Every oak has roots.

II. If the notion C has a part contained in A, that part will likewise be so in B, because the notion A is wholly included in the notion B, *Fig*. 49 and 50.

Fig. 49.

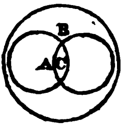
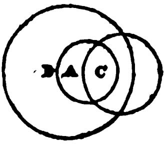


Fig. 50.



Hence results the second form of syllogism:

Every A is B:
But Some C is A:
Therefore Some C is B.

If the notion C were entirely out of the notion A, nothing would follow with respect to the notion B: it might happen that notion C should be entirely out of B (*Fig*. 51), or wholly in B (*Fig*. 52), or partly only in B (*Fig*. 53), so that no conclusion could be drawn.

Fig. 51.

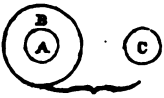


Fig. 52.

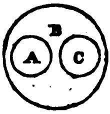
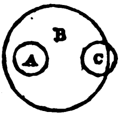


Fig. 53.



But No C is B, or [illegible]
Therefore No C is A.

IV. If the notion C has a part out of the notion B, that same part will certainly likewise be out of the notion A, because this last is wholly in the notion B (*Fig*. 54). Hence this form of syllogism:

Every A is B:
But Some C is not B:
Therefore Some C is not A.

V. If the notion C contains the whole of notion B, part of notion C will certainly fall into notion A (*Fig*. 55). Hence this form of syllogism:

Every A is B:
But Every B is C:
Therefore Some C is A.

No other form is possible, while the first proposition is affirmative and

Let us now suppose the first pro
negative and universal; namely,

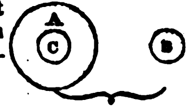
No A is B.

It is represented in *Fig*. 54, where
entirely out of notion B; and the f
will furnish conclusions:

I. If notion C is entirely in no-

II. If notion C is entirely comprehended in notion A, it must also be entirely excluded from notion B (*Fig.* 57). Hence a syllogism of this form:

Fig. 57.



No A is B:
But Every C is A:
Therefore No C is B.

III. If notion C has a part contained in notion A, that part must certainly be out of notion B; as in *Fig.* 58, or in *Fig.* 59, and 60. Hence a syllogism of this form:

No A is B:
But Some C is A, or some A is C:
Therefore Some C is not B.

Fig. 58.

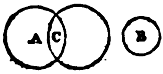


Fig. 59.

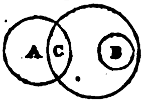
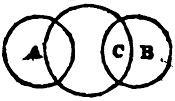


Fig. 60.



IV. In like manner, if notion C has a part contained in B, that part will certainly be out of A; as in *Fig.* 61, as also *Fig.* 62, and 63. Hence the following syllogism:

No A is B:
But Some C is B, or some B is C:
Therefore Some C is not A.

Fig. 61.

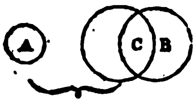


Fig. 62.

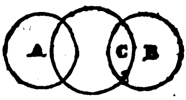
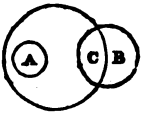


Fig. 63.



As to the other forms, in which the first proposition is particular, affirmative, or negative, I shall show, in another Letter, how they may be represented by figures.

17th February, 1761.

LETTER CIV.

Different Forms of Syllogisms, whose first Proposition is particular.

In the preceding Letter I have presented you with the different forms of syllogisms, or simple reasonings, which derive their origin from the first proposition, when it is universal, affirmative, or negative. It still remains that I lay before you those syllogisms whose first proposition is particular, affirmative, or negative, in order to have all possible forms of syllogism that lead to a fair conclusion.

Let, then, the first proposition, affirmative and particular, be expressed in this general form—

Some A is B (*see Fig.* 45);

in which a part of the notion A is contained in the notion B.

Let us introduce a third notion C, which, being referred to notion A, will either be contained in notion A, as in *Fig.* 64, 65, and 66; or will have a part in the notion A, as in *Fig.* 67, 68, and 69; or will be entirely out of notion A, as in *Fig.* 70, 71, and 72. No conclusion can be drawn in any of these cases, as it might be possible for notion C to be entirely within notion B, or in part, or not at all.

Fig. 64.

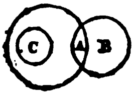


Fig. 65.

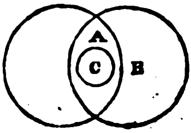


Fig. 66.

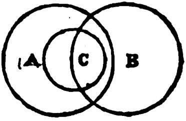


Fig. 67.

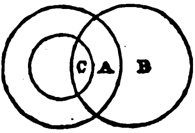


Fig. 68.

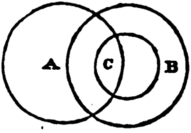


Fig. 69.

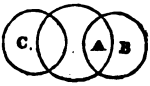


Fig. 70.

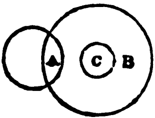


Fig. 71.

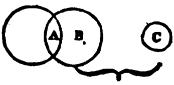
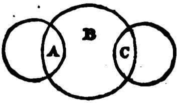


Fig. 72.



But if notion C contains in itself notion A, it is certain that it will likewise contain a part of notion B, as in *Fig.* 73 and 74. Hence results this form of syllogism:

Some A is B:
But Every A is C:
Therefore Some C is B.

Fig. 73.

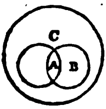
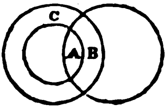


Fig. 74.



It is the same when we compare notion C with notion B: we can draw no conclusion unless notion C contains notion B entirely (*Fig.* 75 and 76); for

Fig. 75.

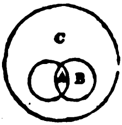
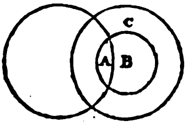


Fig. 76.



in that case, as notion A has a part contained in notion B, the same part will then certainly be con-negative and particular, namely,

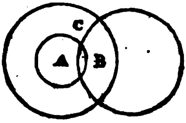
Some A is not B.

It is represented in *Fig.* 77, in whi
of notion A is out of notion B.

In this case, if the third notion
tains notion A entirely, it will cert
part out of notion B, as in *Fig.* 7
gives this syllogism:

Some A is not B:
But Every A is C:
Therefore Some C is not B.

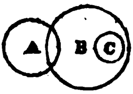
Fig. 78.



F

Again, if notion C is wholly in
B, or A has a part out of B, tha
likewise certainly be out of C (

Fig. 80.



Fi

I. Every A is B:
But Every C is A:
Therefore Every C is B.

II. Every A is B:
But Some C is A:
Therefore Some C is B.

III. Every A is B:
But No C is B:
Therefore No C is A.

IV. Every A is B:
But No B is C:
Therefore No C is A.

V. Every A is B:
But Some C is not B.
Therefore Some C is not A.

VI. Every A is B:
But Every B is C:
Therefore Some C is A.

VII. No A is B:
But Every C is A:
Therefore No C is B.

VIII. No A is B:
But Every C is B:
Therefore No C is A.

IX. No A is B;
But Some C is A:
Therefore Some C is not B.

X. No A is B:
But Some A is C:
Therefore Some C is not B.

XI. No A is B:
But Some C is B:
Therefore Some C is not A.

XII. No A is B:
But Some B is C:
Therefore Some C is not A.

XIII. Some A is B:
But Every A is C:
Therefore Some C is B.

XIV. Some A is B:
But Every B is C:
Therefore Some C is A.

XV. Some A is not B:
But Every A is C:
Therefore Some C is not B.

XVI. Some A is not B:
But Every C is B:
Therefore Some A is not C.

XVII. Every A is B:
But Some A is C:
Therefore Some C is B.

XVIII. No A is B:
But Every A is C:
Therefore Some C is not B.

XIX. No A is B:
But Every B is C:
Therefore Some C is not A.

XX. Every A is B:
But Every A is C:
Therefore Some C is B.

The foundation of all these
two principles, respecting the
and *contained.*

I. *Whatever is in the thing co*
be in the thing containing.

II. *Whatever is out of the con*
be out of the contained.

Thus, in the last form, where
tained entirely in notion B, it is
contained in the notion C, or
that some part of notion C will c
in notion B, so that some C is

Every syllogism, then, consis
tions; the two first of which ar
and the third the *conclusion.*
of all these forms to direct ou
that if the premises are both
infallibly is so.

This is likewise the only me
unknown truths. Every truth
conclusion of a syllogism, whos
bitably true. Permit me only
mer of the premises is called th
and the other the *minor.*

sitions; the two first are called premises, and the third the conclusion. Now the force of the nineteen forms laid down consists in this property common to them all, that if the two first propositions, or the premises, are true, you may rest confidently assured of the truth of the conclusion.

Let us consider, for example, the following syllogism.

NO VIRTUOUS MAN IS A SLANDERER:
But SOME SLANDERERS ARE LEARNED MEN:
Therefore SOME LEARNED MEN ARE NOT VIRTUOUS.

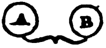
Whenever you allow me the two first propositions, you are obliged to allow the third, which necessarily follows from it.

This syllogism belongs to form XII. The same thing holds with regard to all the others which I have laid down, and which the figures whereby I have represented them render sensible. Here we are presented with three notions, *Fig.* 82, that of virtuous men, that of slanderers, and that of learned men.

Fig. 82.

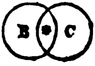
Let the space A represent the first, space B the second, and space C the third. It being said, in the first proposition, that no virtuous man is a slanderer, we maintain that nothing contained in the notion of the virtuous man, that is, in the space A, is comprehended in the notion of the slanderer, that is, space B; therefore space A is wholly out of space B (see *Fig.* 83).

Fig. 83.



But it is said, in the second proposition, that some men comprehended in notion B are likewise contained in that of learned, that is, in space C; or else, you may say that part of space B is within space C, *Fig.* 84, where the part of space B included in C is marked with an *; which will be likewise part of space C. Since, therefore, some part of space C is in B,

Fig. 84.



and that the whole space B is out of space A, it is evident that the same part of space C must likewise be out of space A, that is, *some learned men are not virtuous*.

It must be carefully remarked, that this conclusion respects only the part * of notion C, which is comprehended in notion B; for as to the rest, it is uncertain whether it be likewise excluded from notion A, as in *Fig*. 85, or wholly contained in it, as in *Fig*. 86, or only in part, as in *Fig*. 87.

Fig. 85.

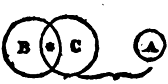


Fig. 86.

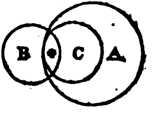
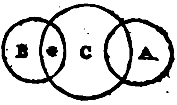


Fig. 87.



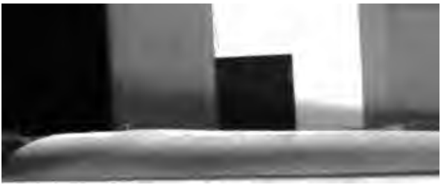
Now, this being left uncertain, the remainder of space C falls not at all under consideration; the conclusion is limited to that only which is certain, that is to say, the same part of space C contained in space B is certainly out of space A, for this last is wholly out of space B.

The justness of all the other forms of syllogism may be demonstrated in like manner; but all those which deviate from the nineteen forms laid down, or which are not comprehended under them, are destitute of foundation, and lead to error and falsehood.

You will clearly discern the fault of such a syllogism, by an example, not reducible to any of the nineteen forms:

SOME LEARNED MEN ARE MISERS:
But NO MISER IS VIRTUOUS:
Therefore SOME VIRTUOUS MEN ARE NOT LEARNED.

This third proposition may perhaps be true, but it does not follow from the premises. They too (the premises) may very well be true, and in the present instance they actually are so: but the third



is not, for that, a fair conclusion; because it is contrary to the nature of just syllogism, in which the conclusion always must be true, when the premises are so. Accordingly, the fault of the form above proposed is immediately discovered, by casting your eyes on *Fig*. 82. Let space A contain all the learned, space B all the avaricious, and space C all the virtuous. Now, the first proposition is represented by *Fig*. 88, in which part * of space A (the learned) is contained in space B (the avaricious); but it by no means follows, *Fig*. 89, that part of space C must be out of space A.

Fig. 88.

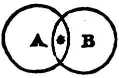
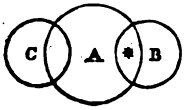


Fig. 89.



It is even possible for space C to be entirely within space A, as in *Fig*. 90, or entirely out of it, as in *Fig*. 91, and at the same time entirely out of space B.

Fig. 90.

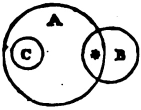
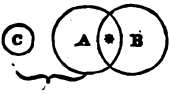


Fig. 91.



A syllogism of this form, accordingly, is totally false and absurd.

Another example will put the matter beyond a doubt:

SOME TREES ARE OAKS:
But NO OAK IS A FIR:
Therefore SOME FIRS ARE NOT TREES.

This form is precisely the same with the preced-

from certain known truths, you
unknown; and that all the reas
demonstrate so many truths in
reduced to formal syllogisms.
however, that our reasonings sh
posed in the syllogistic form,
mental principles be the same.
discourse, and in writing, we r
of avoiding syllogism.

I must further remark, that
premises brings forward that o
does not thence necessarily foll
or both of the premises are fa
must be so likewise; but it is ce
conclusion is false, one of the
absolutely must be false; for if
would be impossible that the co
false. I have still some further
mit to you on this subject, whic
of the certainty of all the know

24th February, 1761.

LETTER CV

and each proposition two notions, or terms; it must be considered that each term is twice employed in it, as in the following example:

EVERY A is B:
But EVERY A is C;
Therefore SOME C is B.

The three notions are marked by the letters A, B, C, which are the three terms of this syllogism; of which the term A enters into the first and second proposition, the term B into the first and third proposition, and the term C into the second and third proposition.

II. You must carefully distinguish these three terms of every syllogism. Two of them, namely, B and C, enter into the conclusion, the one of which, C, is the *subject*, and the other, B, the *attribute*, or *predicate*. In logic, the subject of the conclusion, C, is called the *minor term*, and the *predicate* of the conclusion, B, the *major term*. But the third notion, or the term A, is found in both premises, and it is combined with both the other terms in the conclusion. This term A is called the *mean* or *medium term*. Thus, in the following example:

NO MISER IS VIRTUOUS:
But SOME LEARNED MEN ARE MISERS:
Therefore SOME LEARNED MEN ARE NOT VIRTUOUS.

The notion *learned* is the minor term, that of *virtuous* is the major, and the notion of *miser* is the mean term.

III. As to the order of the propositions, it is a matter of indifference which of the premises is in the first or second place, provided the conclusion holds the last, it being the consequence from the premises. Logicians have, however, thought proper to lay down this rule:

The first proposition is always that which contains the predicate of the conclusion, or the major term: for this is the reason that we give to this proposition the name of the major proposition.

the mean term, with the minor
the conclusion.

IV. Syllogisms are distingui
figures, according as the mea
place of *subject*, or *attribute*, in

Logicians have established
gisms, which are thus defined:

The *first figure* is that in wh
the subject in the major propos
cate in the minor.

The *second figure*, that in wh
the predicate in both the major
minor.

The *third figure*, that in whic
the subject in both the major an
Finally,

The *fourth figure* is that in
is the predicate in the major
subject in the minor.

Let P be the minor term, or
sion; Q the major term, or pre
sion; and M the mean term:
syllogism will be represented i
ing:

Figure Third.

Major Proposition	M	———	Q
Minor Proposition	M	———	P
Conclusion	P	———	Q

Figure Fourth.

Major Proposition	Q	———	M
Minor Proposition	M	———	P
Conclusion	P	———	Q

V. Again, according as the propositions themselves are universal or particular, affirmative or negative, each figure contains several forms, called *modes*. In order the more clearly to represent these modes of each figure, we mark by the letter A universal affirmative propositions; by the letter E, universal negative propositions; by the letter I, particular affirmative propositions; and, finally, by the letter O, particular negative propositions: or else,

A represents a universal affirmative proposition.
E represents a universal negative proposition.
I represents a particular affirmative proposition.
O represents a particular negative proposition.

VI. Hence our nineteen forms of syllogism above described are reducible to the four figures which I have just laid down, as in the following tables:

I. Modes of the First Figure.

1st Mode. A. A. A. Every M is Q: But Every P is M: Therefore Every P is Q.	2d Mode. A. I. I. Every M is Q: But Some P is M: Therefore Some P is Q.
3d Mode. E. A. E. No M is Q: But Every P is M: Therefore No P is Q.	4th Mode. E. I. O. No M is Q: But Some P is M: Therefore Some P is not Q.

II. Modes of the Second Figure.

1st Mode.
A. E. E.
Every Q is M:
But No P is M:
Therefore No P is Q.

2d Mode.
A. O. O.
Every Q is M:
But Some P is not M:
Therefore Some P is not Q.

3d Mode.
E. A. E.
No Q is M:
But Every P is M:
Therefore No P is Q.

4th Mode.
E. I. O.
No Q is M:
But Some P is M:
Therefore Some P is not Q.

III. Modes of the Third Figure.

1st Mode.
A. A. I.
Every M is Q:
But Every M is P:
Therefore Some P is Q.

2d Mode.
I. A. I.
Some M is Q:
But Every M is P:
Therefore Some P is Q.

3d Mode.
A. I. I.
Every M is Q:
But Some M is P:
Therefore Some P is Q.

4th Mode.
E. A. O.
No M is Q:
But Every M is P:
Therefore Some P is not Q.

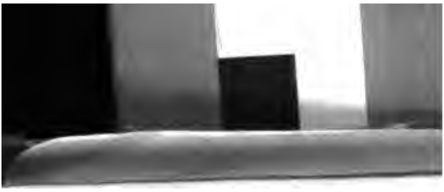
5th Mode.
E. I. O.
No M is Q:
But Some M is P:
Therefore Some P is not Q.

6th Mode.
O. A. O.
Some M is not Q
But Every M is P:
Therefore Some P is not

IV. Modes of the Fourth Figure.

1st Mode.
A. A. I.
Every Q is M:
But Every M is P:
Therefore Some P is Q.

2d Mode.
I. A. I.
Some Q is
But Every M is
Therefore Some P is



3d Mode.
A. E. E.
Every Q is M:
But No M is P:
Therefore No P is Q.

4th Mode.
E. A. O.
No Q is M:
But Every M is P:
Therefore Some P is not Q.

5th Mode.
E. I. O.
No Q is M:
But Some M is P:
Therefore Some P is not Q.

You see, then, that the first figure has four modes, the second four, the third six, the fourth five; so that the whole of these modes together is *nineteen*, being precisely the same forms which I have above explained, and have just now disposed in the four figures. In other respects the justness of each of these modes has been already demonstrated by the spaces which I employed to mark the notions. The only difference consists in this, that here I make use of the letters P, Q, M, instead of A, B, C.

28th February, 1761.

LETTER CVII.

Observations and Reflections on the different Modes of Syllogism.

I FLATTER myself that the following reflections will contribute not a little to place the nature of syllogisms in a clearer light. You must pay particular attention to the species of the propositions which compose the syllogisms of each of our four figures, that is to say, whether they are,

1. Universal affirmative, the sign of which is A; or,
2. Universal negative, the sign of which is E; or,

3 Particular affirmative, the sign of which is I; or, finally,

4. Particular negative, the sign of which is O; and you will readily admit the justness of the following reflections :—

I. In no one instance are both premises negative propositions. Logicians have hence formed this rule :

From two negative propositions no conclusion can be drawn.

The reason is evident; for laying down P and Q as the terms of the conclusion, and M as the mean term, if both premises are negative, the affirmation is, that the notions P and Q are either wholly or in part out of M : it is accordingly impossible to conclude any thing respecting the conformity or disconformity of the notions P and Q. Though I knew from history that the Gauls were not Romans, and that neither were the Celtæ Romans, this would not contribute in the least to inform me whether the Celtæ were Gauls or not. Two negative premises, therefore, lead to no conclusion.

II. Both premises are in no one instance particular propositions ; hence this rule in logic :

From two particular propositions no conclusion can be drawn.

Thus, for example, because some learned men are poor, and some others malevolent, it is impossible to conclude that those who are poor are malevolent, or that they are not so. If you reflect ever so little on the nature of a consequence, you must immediately perceive that two particular premises lead to no conclusion whatever.

III. *If either of the premises is negative, the conclusion too must be negative.*

This is the third rule which logic prescribes. When something is denied in the premises, it is impossible to affirm any thing in the conclusion ; we must absolutely deny there likewise. This rule is

perfectly confirmed by all the laws of syllogism, whose justice has been demonstrated.

IV. *If one of the premises is particular, the conclusion too must be particular.*

This is the fourth rule prescribed in logic. The character of particular propositions being the word *some*, if we speak only of some in one of the premises, it is impossible to speak generally in the conclusion; it must be restricted to some. This rule, likewise, is confirmed by all the laws of syllogism, whose justness is indubitable.

V. *When both premises are affirmative, the conclusion is so likewise. But though both premises may be universal, the conclusion is not always universal; sometimes it is particular only*, as in the *first* mode of figures third and fourth.

VI. Besides universal and particular propositions, we sometimes make use of *singular* propositions, the subject of which is an individual; as, when I say,

Virgil was a great poet,

the name of *Virgil* is not a general notion, containing several beings in itself; it is the proper name of a real individual, who lived a great many years ago. This proposition is called *singular;* and when it is introduced into a syllogism, it is of importance to determine whether we are to consider it as holding the rank of a universal or particular proposition.

VII. Certain authors insist, that a singular proposition must be ranked in the class of particulars; it being considered that a particular proposition speaks only of some beings comprehended in the notion, whereas a universal proposition speaks of all. Now, say these authors, when we speak of only a singular being, this is still less than when we speak of some; and consequently, a singular proposition must be considered as very particular.

VIII. However well founded this reasoning may appear, it cannot be admitted. The essence of a particular proposition consists in this, that it does not speak of all the beings comprehended in the notion of the subject, whereas a universal proposition speaks of all without exception. Thus, when it is said,

Some citizens of Berlin are rich,

the subject of this proposition is the notion of *all the citizens* of Berlin; but this subject is not taken in all its extent—its signification is expressly restricted to *some;* and by this, particular propositions are essentially distinguished from universal, as they turn only on a part of the beings comprehended in their subject.

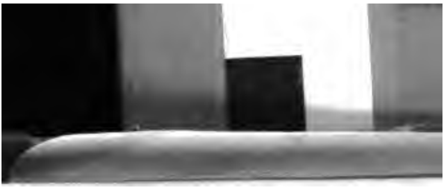
IX. It is clearly evident, from this remark, *that a singular proposition must be considered as universal;* as, in speaking of an individual, say Virgil, it in no respect restricts the notion of the subject, which is Virgil himself, but rather admits it in all its extent; *and for this reason, the same rules which take place in universal propositions apply likewise to singular propositions.* The following is accordingly a very good syllogism:

VOLTAIRE IS A PHILOSOPHER:
But VOLTAIRE IS A POET:
Therefore SOME POETS ARE PHILOSOPHERS.

And it would be faulty if the two premises were particular propositions; but being considered as universal, this syllogism belongs to figure third, and the first mode of the form A. A. I. The individual idea of Voltaire is the mean term, which is the subject of both major and minor; and this is the character of figure third.

X. Finally, I must remark, that hitherto I have spoken only of *simple propositions*, which contain only two notions, the one of which is affirmed or denied, universally or particularly. With respect to *compound propositions*, logic prescribes peculiar rules.

3d March, 1761.



LETTER CVIII.

Hypothetical Propositions, and Syllogisms constructed of them.

We have hitherto considered simple propositions only, or such as contain but two notions, the one of which is the subject, the other the predicate. These propositions can form no other syllogisms, except those which I have laid before you, and which are contained in the four figures above explained. But we likewise frequently employ *compound propositions*, which contain more than two notions, and respecting which other rules are to be observed, in order to deduce fair conclusions from them.

Of these compound propositions, the most common are those which are called *hypothetical*, or *conditional*, which contain two complete propositions, with an affirmation, that *if the one is true, the other is so likewise:* the following is an example of a conditional proposition:

If the gazette speaks truth, peace is not very distant.

Here are two propositions, the first, *the gazette speaks truth*, or, *the gazette is true:* and the other, *peace is not very distant*, or *peace is approaching*.

Now these two propositions must be connected together in such a manner, that if the first is true, the second is so likewise; or it is maintained, that the second proposition is a necessary consequence of the first, so that the former cannot be true, without establishing the truth of the other also. Supposing, then, that the gazettes announce the approach of peace, we are warranted in saying, that, *if the gazettes are true, peace must be at hand*.

Without this condition, such a proposition leads to nothing; but if this condition is complied with, then, with the addition of some other proposition, there are two ways of drawing a conclusion from it: 1st. When some person assures us, *that the gazette speaks truth;* for hence we conclude *that peace is near:* 2d. When we are told, *that peace is still very distant;* then we make no hesitation in thence concluding *that the gazette does not speak truth.*

You see that these two conclusions are general, and give two forms of hypothetical or conditional syllogisms, which may be thus represented:

First Form.

If A IS B, C WILL BE D:
But A IS B:
Therefore C IS D.

Second Form.

If A IS B, C WILL BE D:
But C IS NOT D:
Therefore A IS NOT B.

These two are the only just conclusions; and you must be carefully on your guard against the fallacy of the two following forms:

First erroneous Form.

If A IS B, C WILL BE D:
But A IS NOT B:
Therefore C IS NOT D.

Second erroneous Form.

If A IS B, C WILL BE D:
But C IS D:
Therefore A IS B.

These are both fallacious. In the example adduced I should reason inconclusively, if I argued in this manner:

If THE GAZETTE SPEAKS TRUTH, PEACE IS APPROACHING:
But THE GAZETTE DOES NOT SPEAK TRUTH:
Therefore PEACE IS NOT APPROACHING.

It is undoubtedly true that the gazette may not speak truth; nevertheless, it is very possible that peace may be approaching.

The other form is equally erroneous:

If THE GAZETTE IS TRUE, PEACE APPROACHES:
But PEACE APPROACHES:
Therefore THE GAZETTE IS TRUE.

Let us suppose that this consolatory truth, *peace approaches*, were revealed to us, so as to be put beyond the possibility of doubt, it would by no means follow that gazettes are true, or that they never contain untruths. I hope at least that peace is at hand, though I am very far from putting confidence in the truth of gazettes.

These two last forms of syllogisms, therefore, are fallacious; but the two preceding are certainly good, and never lead into error, provided that the first conditional proposition is true, or that the last part be a necessary consequence of the first.

Of this conditional proposition—

If A is B, C will be D;

the first part, *A is B*, is called the *antecedent*, and the other, *C will be D*, the *consequent*. Logic prescribes the two following rules to direct us in this style of reasoning:

I. *Whoever admits the antecedent must likewise admit the consequent.*

II. *Whoever denies or rejects the consequent must likewise deny or reject the antecedent.*

But you may very well deny the antecedent without denying the consequent, and likewise admit the consequent without admitting the antecedent.

There are still other compound propositions, of which also syllogisms may be formed. It will perhaps be sufficient to produce a single example. Having this proposition,—

Every substance is body or spirit,—

the conclusion will run in the following manner:

I. But such a substance is not body;
Therefore it is spirit.

LETTER CI

Of the Impression of Sensat

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logic, whose object it is to lay
for right reasoning, I must sti
longer on the subject of ideas.

We undoubtedly derive them
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the idea of any object, the soul
the object ceases to act on o
the sensation, by which the
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ceiving would answer little or no purpose; if we lost every moment the recollection of ideas once perceived, we should always be in the state of new-born infants, that is, in a state of the most profound ignorance. Reminiscence, then, is the most precious gift which the Creator has bestowed on the soul of man, and here its spirituality shines in the brightest lustre; for by means of this faculty the soul gradually rises to the attainment of knowledge the most sublime.

But though recollected ideas represent to us the same objects which perceived ideas do, they differ from them in this, that they are not accompanied with the sensation, nor with the conviction, that the objects really exist. If you have once been a spectator of a conflagration, you can recall the idea of it whenever you will, without imagining, however, that there really is one. It is even possible, that for a very long time you may not have thought of such a conflagration, but without having lost the power of recalling the idea of it.

It is the same with respect to all the ideas which we have once perceived; but it frequently happens that we lose almost entirely the recollection, or, in other words, forget them. We remark, nevertheless, a very great difference between ideas forgotten and ideas wholly unknown, or such as we never had. With respect to the first, as soon as the same object presents itself afresh to our senses, we much more easily catch the idea of it, and we recollect perfectly, that it is the same which we had forgotten: this would not be the case had we never possessed it.

It is here the materialists boast of having found a demonstration of their opinions. They conclude from it, that it is extremely clear, the soul is nothing else but a subtile matter, on which external objects are capable of making some slight impression, by means of the senses: that this impression is nothing

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solve all the perplexing questions respecting the origin of evil, the permission of sin, and the existence of all the calamities by which the world is oppressed; their great and only source is human liberty.

10*th March*, 1761.

LETTER CX.

Of the Origin and Permission of Evil; and of Sin.

The origin and permission of evil in the world is an article which has in all ages greatly perplexed theologians and philosophers. To believe that God, a Being supremely good, should have created this world, and to see it overwhelmed with such a variety of evil, appears so contradictory, that some found themselves reduced to the necessity of admitting two principles, the one supremely good, the other supremely evil. This was the opinion entertained by the ancient heretics known in history by the name of *Manicheans;* who, seeing no other way of accounting for the origin of evil, were reduced to this extremity. Though the question be extremely complicated, this single remark, that liberty is a quality essential to spirits, dispels at once a great part of the difficulties which would otherwise be insurmountable.

In truth, when God had created man, it was too late to prevent sin, his liberty being susceptible of no constraint. But, I shall be told, it would have been better not to create such and such men, or spirits, who, as God must have foreseen, would abuse their liberty, and plunge into sin. I should deem it rather rash to enter upon this discussion, and to pretend to judge of the choice which God might have been able to make in creating spirits; and perhaps the plan of the universe required the existence of

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other means which God employs to reclaim us from our wanderings, that, on this side, we may rest confidently assured that God has omitted nothing which could have prevented the malignant explosions of men, and of other reasonable beings.

But those who bewilder themselves in such doubts respecting the origin and the permission of evil in the world, perpetually confound the corporeal with the spiritual world; they imagine that spirits are, as bodies, susceptible of constraint. Severe discipline is frequently capable of preventing, among the children of a family, the soldiers of an army, or the inhabitants of a city, the open eruption of perverse dispositions; but it must be carefully remarked that this constraint extends only to what is corporeal; it in no respect restrains the spirit from being as vicious and as malignant as if it enjoyed the most unbounded license.

Human governments must rest contented with this exterior or apparent tranquillity, and give themselves little trouble about the real dispositions of men's minds; but before God the thoughts all lie open, and perverse inclinations, however concealed from men, are as abominable in his sight as if they had broken out into the most atrocious actions Men suffer themselves to be dazzled by false appearances; but God has respect to the real dispositions of every spirit, according as they are virtuous or vicious, independently of the actions which flow from them.

The Holy Scriptures contain to this purpose the most pointed declarations, and inform us that he who meditates only the destruction of his neighbour, suffering himself to be hurried away by a spirit of hatred, is as criminal in the sight of God as the actual murderer; and that he who indulges a covetous desire of another's property is, in His estimation, as much a thief as he who really steals.

In this respect, therefore, the government of God reflection of which we ought

14*th March*, 1761.

LETTER C

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many corrupted men and spirits ought not to form any objection against the perfection of this world, much less be considered as an imputation of the Supreme Being.

A spirit, the devil not excepted, is always a being, excellent, and infinitely superior to every thing that can be conceived in the corporeal world; and this world, as far as it contains an infinite number of spirits, of all orders, is always a work of the highest perfection. Now, all spirits being essentially free, criminality was possible from the commencement of their existence, and could not be prevented even by the Divine Omnipotence. Besides, spirits are the authors of the evils which necessarily result from sin, every free agent being always the only author of the evil which he commits; and, consequently, these evils cannot be imputed to the Creator; as, among men, the workman who makes the sword is not responsible for the mischief that is done with it. Thus, with respect to the moral evils which prevail in the world, the sovereign goodness of God is sufficiently justified.

The other class, that of *physical evils*, contains all the calamities and miseries to which men are exposed in this world. It is admitted that most of these are a necessary consequence of the malice and other vicious propensities with which men as well as other spirits are infected; but as these consequences are communicated by means of bodies, it is asked, Why God should permit to wicked spirits the power of acting so efficaciously on bodies, and of employing them as instruments to execute their pernicious purposes? A father who saw his son on the point of committing a murder would snatch the sword out of his hand, and prevent the perpetration of a crime so heinous. I have already observed, that this abandoned son is equally guilty before God, whether he has actually accomplished his design, or only made ineffectual efforts to execute it; and the father, who prevented him, does not thereby render him better.

We may nevertheless confidently maintain, that God does not permit a free course to the wickedness of man. Did nothing resist the execution of all the pernicious purposes of the human heart, how miserable should we be! We frequently see that the wicked have great difficulties to encounter; and though they should succeed, they have no power over the consequences of their actions, which always depend on so many other circumstances that, in the issue, they produce the directly opposite effect from what was intended. It cannot be denied, at the same time, that there may result from these calamities and miseries to torment mankind; and it is imagined that the world would be infinitely better governed were God to interpose an effectual restraint to the wickedness and audacity of men.

It would undoubtedly be very easy for God to crush to death a tyrant before he could realize his cruel and oppressive designs; or to strike dumb an unjust judge who was going to pronounce an iniquitous sentence. We might then live quietly, and enjoy all the comforts of life, supposing God were to grant us the blessings of health, and all the good things we could wish for: our happiness would thus be perfect. On this plan they would have the world governed, in order to render us all happy: the wicked disabled to perpetrate their criminal purposes, and the good in possession of the peaceful enjoyment of all the blessings which they can desire.

It is believed, and with good reason, that God wishes the happiness of men; and it is matter of surprise that this world should be so different from the plan which is imagined the most proper for the attainment of this end. We rather see the wicked frequently enjoying, not only all the advantages of this life, but put in a condition to execute their machinations, to the confusion and distress of persons of worth; while the good are oppressed and overwhelmed by the most sensible evils, pains, diseases, mortifications, loss of goods, and, in general, by every species of calamity; and that at last the good as well as the bad must infallibly die, which appears to be the greatest of all evils.

Looking on the world in this point of view, one is tempted to call in question the supreme wisdom and goodness of the Creator; but it is a hazard which we must take great care to avoid.

7th March, 1761.

LETTER CXII.

Reply to Complaints of the Existence of Physical Evil.

Supposing our existence limited to the present life, the possession of the good things of this world and the enjoyment of every delight would be very far from filling up the measure of our happiness. All are agreed, that true felicity consists in mental tranquillity and satisfaction, which are seldom if ever accompanied with that brilliancy of condition which is considered as such an inestimable blessing by those who judge only from appearances.

The insufficiency of temporal good things to render us happy becomes still more manifest when we come to reflect on our real destination. Death does not put a period to our existence, it rather transmits us into another life, which is to endure for ever. The faculties of our soul, and our attainments in knowledge, will then no doubt be carried to the highest perfection; and it is on this new state that our real happiness depends, and this state cannot be happy without virtue.

The infinite perfections of the Supreme Being, which we now perceive only as through a thick cloud, shall then shine in the brightest lustre, and shall become the principal object of our contemplation, admiration, and adoration. There, not only shall our understanding find the most inexhaustible stores of pure and perfect knowledge, but we shall be permitted to hope for admission into favour with the Supreme Being, and to aspire after the most endearing expressions of his love. How happy do we reckon the peculiar favourites of a great prince, especially if he is really great, though the favours which he bestows are marred by many infusions of bitterness! What will it then be, in the life to come, when God himself shall *shed abroad his love in our hearts*—a love, the effects of which shall never be interrupted nor destroyed? This shall thenceforward constitute a felicity infinitely surpassing all that we can conceive.

In order to participate in these inexpressible favours, flowing from the love of the Supreme Being, it is natural that, on our part, we should be penetrated with sentiments of the most lively affection to him. This blessed union absolutely requires in us a certain disposition, without which we should be incapable of participating in it; and this disposition consists in virtue, the basis of which is the love of God, and that of our neighbour. The attainment of virtue, then, should be our chief, our only object in this life, where we exist but for this end—to prepare for, and to render ourselves worthy of, partaking in supreme and eternal felicity.

In this point of view, we must form a judgment of the events which befall us in this life. It is not the possession of the good things of this world that renders us happy; it is rather a situation which most effectually conducts to virtue. If prosperity were the certain means of rendering us happy, we might be suffered to complain of adversity; but adversity may rather have the effect of confirming our virtue: and, in this view, all the complaints of men respecting the physical evils of life are likewise completely done away.

You have no difficulty, then, in comprehending that God had the most solid reasons for admitting into the world so many calamities and miseries, as the whole obviously contributes to our salvation. It is unquestionably true that these calamities are, for the most part, natural consequences of human corruption; but it is in this very thing that we must principally admire the wisdom of the Supreme Being, who knows how to overrule the most vicious actions for our final happiness.

Many good people would not have reached such a sublimity of virtue, had they not been oppressed and tormented by cruelty and injustice.

I have already remarked, that bad actions are such only with regard to those who commit them: the determination of their soul alone is criminal, the action itself being a thing purely corporeal, inasmuch as, considered independently of the person who commits it, there is nothing either good or evil in the case. A mason falling from the roof of a house upon a man as certainly kills him as the most determined assassin. The action is absolutely the same: but the mason is not guilty in the slightest degree; whereas the assassin deserves the severest punishment. Thus, however criminal actions may be with regard to those who commit them, we must consider them in quite a different light as they affect ourselves, or produce an influence on our situation.

We ought therefore to reflect, that nothing can befall us but what is perfectly consonant to the sovereign wisdom of God. The wicked may be guilty of injustice towards us, but we cannot upon the whole suffer from it; no one can ever injure us, though he may greatly hurt himself; and in every thing that comes to pass, we ought always to acknowledge God, as if it befell us immediately by his express appointment. We may, moreover, rest assured that it is not from caprice, or merely to vex us, that God disposes the events in which we are concerned, but that they must infallibly terminate in our true happiness. Those who consider all events in this light will soon have the satisfaction of being convinced that God exercises a peculiar care over them.

21*st March*, 1761.

LETTER CXIII.

The real Destination of Man; Usefulness and Necessity of Adversity.

I hope you have no doubts remaining with respect to this great question,—How the evils of this world can be reconciled to the supreme wisdom and goodness of the Creator? The solution of it is incontestably founded on the real destination of man, and of other intelligent beings, whose existence is not limited to this life. The moment that we lose sight of this important truth, we find ourselves involved in the greatest perplexity; and if man were created only for this life, it would assuredly be impossible to establish a consistency between the perfections of God and the distresses and miseries with which this world is oppressed. Those miseries would be but too real; and it were absolutely impossible to explain, how the prosperity of the wicked, and the misery of so many good people, could consist with the Divine justice.

But no sooner do we reflect that this life is but the commencement of our existence, and that it is a preparation for one that shall endure eternally, than the face of things is entirely changed, and we are obliged to form a very different judgment of the evils with which this life appears to be overspread. I have already remarked, that the prosperity which we enjoy in this world is the reverse of a suitable preparation for a future life, and for rendering us worthy of the felicity which there awaits us. However important to our happiness the possession of the good things of this world may appear, this quality pertains to them only in so far as they are impressed with the signatures of Divine goodness, independent of which no earthly possessions could constitute our felicity.

Real happiness is to be found only in God himself; all other delights are but an empty shade, and are capable of yielding only a momentary satisfaction. Accordingly we see that those who enjoy them in the greatest abundance are quickly satiated; and this apparent felicity serves only to inflame their desires and to disorder their passions, by estranging them from the Supreme Good, instead of bringing them nearer to Him. But true felicity consists in a perfect union with God, which cannot subsist without a love and a confidence in his goodness transcending all things; and this love requires a certain disposition of soul, for which we must be making preparation in this life.

This disposition is virtue, the foundation of which is contained in these two great precepts:

> *Thou shalt love the Lord thy God with all thy heart, with all thy soul, with all thy strength, and with all thy mind;*

and the other, which is like unto it:

> *Thou shalt love thy neighbour as thyself.*

Every other disposition of soul which deviates from these two precepts is vicious, and absolutely unworthy to partake of true happiness. It is as impossible for a vicious man to enjoy happiness in the life to come, as for a deaf man to relish the pleasure of an exquisite piece of music. He must be for ever excluded from it, not by an arbitrary decree of God, but by the very nature of the thing; a vicious

man not being, from his own nature, susceptible of supreme felicity.

If we consider the order and economy of the world in this point of view, nothing can be more perfectly disposed for the attainment of this great end. All events, the calamities themselves which we undergo, are the most suitable means for conducting us to true happiness; and in this respect it may be with truth affirmed, that this is indeed the best world possible, as every thing in it concurs to promote our eternal salvation. When I reflect that nothing befalls me by chance; but that every event is directed by Providence, in the view of rendering me truly and everlastingly happy, how ought this consideration to raise my thoughts to God, and to replenish my soul with the purest affection.

But however efficacious these means may be in themselves, they exercise no force upon our minds, to which liberty is so essential that no degree of constraint can possibly take place. Experience, accordingly, frequently demonstrates, that our attachment to the objects of sense renders us too vicious to listen to these salutary admonitions. Abuse of the means which would have improved our virtue plunges us deeper and deeper into vice, and hurries us aside from the only path that leads us to happiness.

24*th March*, 1761.

LETTER CXIV.

Of true Happiness. Conversion of Sinners. Reply to Objections on the Subject.

THE holy life of the apostles, and of the other primitive Christians, appears to me an irresistible proof of the truth of the Christian religion. If true happiness consists in union with the Supreme Being, which it is impossible for a moment to doubt, the enjoyment of this happiness necessarily requires, on our part, a certain disposition, founded on supreme love to God, and the most perfect charity towards our neighbour; so that all those who are destitute of this disposition destroy their own pretensions to celestial felicity; and wicked men are from their very nature necessarily excluded from it, it being impossible for God himself to render them happy. For the Divine Omnipotence extends only to things which are in their nature possible, and liberty is so essential to spirits that no degree of constraint can take place with respect to them.

It is only by motives, therefore, that spirits can be determined to that which is good; now, what motives could be proposed to the apostles and other disciples of Jesus Christ, to embrace a virtuous life, more powerful than the instructions of their divine Master, his miracles, his sufferings, his death and resurrection, of which they were witnesses. All these striking events, united to a doctrine the most sublime, must have excited in their hearts the most fervent love and the most profound veneration for God, whom they could not but consider and adore as at once their heavenly Father and the absolute Lord of the whole universe. These lively impressions must necessarily have stifled in their breasts every vicious propensity, and have confirmed them more and more in the practice of virtue.

This salutary effect on the minds of the apostles has nothing in it of itself miraculous, or which encroaches in the smallest degree on their liberty, though the events be supernatural. The great requisite was simply a heart docile and uncorrupted by vice and passion. The mission, then, of Jesus Christ into the world produced in the minds of the apostles this disposition, so necessary to the attainment and the enjoyment of supreme happiness; and that mission still supplies the same motives to pursue the

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as if I were maintaining that the power of man is sufficient for his conversion; but this reproach affects me not, as I am conscious of intending to place the goodness of God in its clearest light. In the work of conversion, man makes perfect use of his liberty, which is unsusceptible of constraint; but man is always determined by motives. Now these motives are suggested by the circumstances and conjunctures of his condition. They depend entirely on Divine Providence, which regulates all events conformably to the laws of sovereign wisdom. It is God, therefore, who places men every instant in circumstances the most favourable, and from which they may derive motives the most powerful to produce their conversion; so that men are always indebted to God for the means which promote their salvation.

I have already remarked, that however wicked the actions of men may be, they have no power over their consequences, and that God, when he created the world, arranged the course of all events so that every man should be every instant placed in circumstances to him the most salutary. Happy the man who has wisdom to turn them to good account!

This conviction must operate in us the happiest effects; unbounded love to God, with a firm reliance on his providence, and the purest charity towards our neighbour. This idea of the Supreme Being, as exalted as it is consolatory, ought to replenish our hearts with virtue the most sublime, and effectually prepare us for the enjoyment of life eternal.

28*th March*, 1761.

LETTER CXV.

The true Foundation of Human Knowledge. Sources of Truth, and Classes of Information derived from it.

Having taken the liberty to lay before you my opinion respecting the most important article of human knowledge, I flatter myself it will be sufficient to dissipate the doubts which naturally arise out of the subject, from want of exact ideas of the liberty of spirits.

I shall now have the honour of submitting to your consideration the true foundation of all our knowledge, and the means we have of being assured of the truth and certainty of what we know. We are very far from being always certain of the truth of all our sentiments; for we are but too frequently dazzled by appearances, sometimes exceedingly slight, and whose falsehood we afterward discover. As we are therefore continually in danger of deceiving ourselves, a reasonable man is bound to use every effort to avoid error, though he may not always be so happy as to succeed.

The thing to be here chiefly considered is the solidity of the proofs on which we found our persuasion of any truth whatever; and it is absolutely necessary that we should be in a condition to judge if they are sufficient to convince us or not. For this effect I remark, first, that all truths within our reach are referable to three classes, essentially distinguished from each other.

The first contains the truths of the senses; the second, those of the understanding; and the third, those of belief. Each of these classes requires peculiar proofs of the truths included in it, and in these three classes all human knowledge is comprehended.

Proofs of the first class are reducible to the senses, and are thus expressed:

This is true, for I saw it, or am convinced of it by the evidence of my senses.

It is thus I know that the magnet attracts iron, because I see it, and experience furnishes me with incontestable proofs of the fact. Truths of this class are called *sensible*, because they are founded on the senses, or on experience.

Proofs of the second class are founded on ratiocination:

This is true, for I am able to demonstrate it on principles of just reasoning, or by fair syllogisms.

To this class principally logic is to be referred, which prescribes rules for reasoning consequentially. It is thus we know that the three angles of a rectilineal triangle are together equal to two right angles. In this case I do not say I see it, or that my senses convince me of it; but I am assured of its truth by a process of reasoning. Truths of this class are called *intellectual;* and here we must rank all the truths of geometry, and of the other sciences, inasmuch as they are supported by demonstration. You must be sensible that such truths are wholly different from those of the first class, in support of which we adduce no other proofs but the senses, or experience, which assure us that the fact is so, though we may not know the cause of it. In the example of the magnet, we do not know how the attraction of the iron is a necessary effect of the nature of the magnet and of iron; but we are not the less convinced of the truth of the fact. Truths of the first class are as certain as those of the second, though the proofs which we have of them are entirely different.

I proceed to the third class of truths, that of faith, which we believe because persons worthy of credit relate them; or when we say:

This is true, for several creditable persons have assured us of it.

This class accordingly includes all *historical truths.* You believe, no doubt, that there was formerly a king of Macedon called Alexander the Great, who made himself master of the kingdom of Persia, though you never saw him, and are unable to demonstrate geometrically that such a person ever existed. But we believe it on the authority of the authors who have written his history, and we entertain no doubt of their fidelity. But may it not be possible that these authors have concerted to deceive us? We have every reason to reject such an insinuation; and we are as much convinced of the truth of these facts, at least of a great part of them, as of truths of the first and second classes.

The proofs of these three classes of truths are extremely different; but if they are solid, each in its kind, they must equally produce conviction. You cannot possibly doubt that Russians and Austrians have been at Berlin, though you did not see them: this, then, is to you a truth of the third class, as you believe it on the report of others; but to me it is one of the first class, because I saw them, and conversed with them; and many others were assured of their presence by means of their senses. You have, nevertheless, as complete conviction of the fact as we have.

31*st March*, 1761.

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